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Compilation of 1987 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program

Volume 1 of 3 Volumes:
TABS A - C

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This is the sixth compilation of annual reports for the Navy's ELF Communications System Ecological Monitoring Program. The reports document the progress of ten studies performed during 1987 at the Wisconsin and Michigan Transmitting Facilities. The purpose of the monitoring is to determine whether electromagnetic fields produced by the ELF Communications System will affect resident biota or their ecological relationships. Keywords:

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19. Abstract (Continued)

A. Herbaceous Plant Cover and Tree Studies
Michigan Technological University
Becker, C. T.; Brooks, R. H.; Bruhn, J. N.; Cattelino, P. J.; Gale, M. R.; Holmes, M. J.; Jurgensen, M. F.; Liechty, H. O.; Moore, J. A.; Mroz, G. D.; Reed, D. D.; Reed, E. J.; Richter, D. L.; Zhang, Y. F.

B. Litter Decomposition and Microflora
Michigan Technological University
Bagley, S. T.; Bruhn, J. N.; Pickens, J. B.

C. The Effects of Exposing the Slime Mold <u>Physarum polycephalum</u> to Electromagnetic Fields
University of Wisconsin-Parkside
Goodman, E. M.; Greenebaum, B.

FOREWORD

The U.S. Navy is conducting a long-term program to monitor for possible effects from the operation of its Extremely Low Frequency (ELF) Communications System to resident biota and their ecological relationships. The program is being implemented by IIT Research Institute (IITRI) under contract to the Space and Naval Warfare Systems Command (SPAWAR). IITRI provides engineering support and coordinates the efforts of investigators. Monitoring projects are being carried out through subcontract arrangements between IITRI and study teams at several universities.

This is the sixth compilation of annual reports prepared by university study teams. Each report chronicles the data collection and data analysis activities for a monitoring project during 1987. As in the past, each report has been reviewed by four or more scientific peers. Investigators have considered and addressed reviewer critiques prior to providing their report for printing. Reports have been printed from original copies without change or editing by either IITRI or SPAWAR.

Reports other than this compilation document electromagnetic exposures at study sites and summarize the annual progress of the program. These reports have been prepared on an annual basis since the inception of the program in 1982. All have been provided to the National Technical Information Service for unlimited distribution. The results of monitoring studies have also been presented at scientific meetings and as articles in peer reviewed, scientific journals.

ELF ECOLOGICAL MONITORING PROGRAM
INDEX OF 1987 ANNUAL REPORTS

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ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM: HERBACEOUS PLANT COVER AND TREE STUDIES

The Michigan Study Site

Tasks 5.13/5.14

ANNUAL REPORT 1987

SUBCONTRACT NUMBER: E06549-84-001

PROJECT COORDINATOR: Glenn D. Mroz
Associate Professor
(906/487-2496)

INVESTIGATORS:
Kathy Teahan Becker
Randall H. Brooks
Johann N. Bruhn
Peter J. Cattelino
Margaret Rowan Gale
Michael J. Holmes
Martin F. Jurgensen
Hal O. Liechty
Joni Allen Moore
Glenn D. Mroz
David D. Reed
Elizabeth Jones Reed
Dana L. Richter
Yun F. Zhang

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MICHIGAN TECHNOLOGICAL UNIVERSITY

HOUGHTON, MICHIGAN

ABSTRACT

In 1982, Michigan Technological University initiated research at the Michigan antenna site which would determine whether ELF electromagnetic fields cause changes in forest productivity and health. Work elements were initiated at control, antenna and ground treatment plots to establish a baseline of data that could be used to compare various aspects of these communities both before and after the antenna becomes activated. This approach is the the most rigorous for evaluating possible effects of ELF fields on forest ecosystems.

The overall objectives of the work elements are to determine the impacts of ELF electromagnetic fields on:

1) growth rates of established stands, individual hardwood trees and red pine seedlings,
2) timing of selected phenological events of trees, herbs and mycorrhizal fungi,
3) numbers and kinds of indigenous mycorrhizae on red pine seedlings,
4) nutrient levels of hardwoods and red pine,
5) foliage production in hardwoods,
6) insect and disease status of hardwood and pine stands.

This document details the progress of work in each of these study areas to December 31, 1987.

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INTRODUCTION

Forest vegetation is the dominant cover type on the ELF communications Antenna System area. In 1982, Michigan Technological University initiated research at the Michigan antenna site which would determine whether ELF electromagnetic fields cause changes in forest productivity and health. Work elements examining different aspects of these forest ecosystems were initiated to establish a baseline of data that could be used to make preoperational to operational comparisons evaluating possible ELF field effects on these communities.

The overall objectives of these work elements are to determine the impacts of ELF electromagnetic fields on:

1) growth rates of established stands, individual hardwood trees and red pine seedlings,
2) timing of selected phenological events of trees, herbs and mycorrhizal fungi,
3) numbers and kinds of indigenous mycorrhizae on red pine seedlings,
4) nutrient levels of hardwoods and red pine,
5) foliage production in hardwoods,
6) insect and disease status of hardwood and pine stands.

Ultimately, the question of whether ELF electromagnetic fields measurably impact forest communities will be answered by testing various hypotheses (Table I.1) based on the results of long-term studies.

PROJECT DESIGN

Overview of Experimental Design

Much of the effort in this study has been dedicated to developing a statistically rigorous design to separate what may be very subtle ELF field effects on response variables from the existing natural variability caused by soil, stand and climatic factors (Upland Flora 1985 Report). Consequently to test our hypotheses it has been imperative to directly measure both plant growth and important regulators of the growth process such as tree, stand, and site factors in addition to ELF fields at the sites (Table I.2). These measurements and associated analyses are discussed more fully in the various work element sections of this proposal. Work elements group similar measurements and analyses but are interrelated, with data from several elements often used to test a single hypotheses (Table I.2)

Table I.1. Critical hypotheses that will be tested to fulfill the objectives of the ELF environmental monitoring program Upland Flora project.

I. There is no difference in the level or the pattern of seasonal diameter growth of hardwoods before and after the ELF antenna becomes operational.

II. There is no difference in the level of diameter growth of red pine seedlings before and after the ELF antenna becomes operational.

III. There is no difference in the level or rate of height growth of red pine seedlings before and after the ELF antenna becomes operational.

IV. There is no difference in the rate of growth and phenological development of the herb, Trientalis borealis L., before and after the ELF antenna becomes operational.

V. There is no difference in sporocarp production by mycorrhizal fungi before and after the ELF antenna becomes operational.

VI. There is no difference in the number of different types of mycorrhizal root tips on red pine seedlings before and after the antenna becomes operational.

VII. There is no difference in the total weight and nutrient concentrations of tree litter before and after the ELf antenna becomes operational.

VIII. There is no difference in the total weight and nutrient concentrations of tree litter before and after the ELF antenna becomes operational.

IX. There is no difference in the rate of development of Armillaria root disease on red pine seedlings before and after the ELF antenna becomes operational.

The experimental design integrates direct measures with site variables and electromagnetic field exposure and is a common thread through nearly all studies due to the field design of this project. An understanding of this experimental design is essential because of the similarity in analyses for hypotheses testing and the complexity of the overall project. However, the rationale and progress for measurement sin each work element of this study are unique and will be presented separately.

Field Design

The electromagnetic fields associated with the ELf system will be different at the antenna and ground locations (Anonymous, 1977). As a consequence, forest vegetation at each site could be differentially affected by both above and below ground fields. Therefore, the general approach of the study required plots to be located along a portion of the antenna, at the ground terminal, and at a control location some distance from the antenna.

The experimental design is best described as a split plot in space and time. Each site (control, antenna, and ground) is subjected to a certain level of ELF field exposure and is subdivided into two subplots called stand types (Figure I.1). Hardwood stands and red pine (Pinus resinosa Ait.) plantations comprise the treatments for the second level of the design. Each stand type is replicated three times on a site (ELF field exposure) to control variation. The time factor is the number of years that an experiment is conducted for preoperational to operational comparisons, or the number of sampling periods in one season for year-to-year comparisons. It is necessary to account for time in the experimental design since successive measurements are made on the same whole plots over a long period of time without rerandomization of plots. A combined analysis involving a split plot is space and time is made to determine both the average treatment response (site difference) over all years, and consistency of such responses from year to year (Steel and Torrie 1980).

Figure I.1. Diagram of the control plot as an example of the experimental design units.

Control Site

(PLOT)

Replicate 1	Replicate 2	Replicate 3	(Subplot) Hardwood Stand

sham right of way

Replicate 1	Replicate 2	Replicate 3	(Subplot) Red Pine Plantation

Each site follows this design with one exception. There is no hardwood stand at the ground because required buffer strips would have resulted in the stands being too distant from the ground for meaningful exposure. Thus, on e treatment factor (hardwood stands) is eliminated at the ground. Depending on the variable of interest, the stand type treatment factor may or may not be pertinent. In those cases where measurements are made on only one stand type, it becomes irrelevant and falls out of analysis. All other factors remain unchanged.

Analysis of Covariance

Our experimental design directly controls error in the field to increase precision. Indirect or statistical control can also increase precision and remove potential sources of bias through the use of covariate analysis. This involves the use of covariates which are related to the variable of interest. Covariate analysis removes the effects of an environmental source of variation that would otherwise contribute to the experimental error. The covariate need not be a direct causal agent of the variate, but merely reflect some characteristic of the environment which also influences the variate (Cochran 1957). Thus, determining covariates which are both biologically meaningful as well as independent of treatment effects is one of the most important steps in our analysis.

Covariates under examination vary for a given variable of interest (Table I.2). Most analyses use ambient climatic variables, such as air temperature, soil temperature, soil moisture, precipitation, and relative humidity, as well as those computed from these data, such as air temperature degree days, soil temperature degree days and cumulative precipitation. Depending on the variable of interest, microsite factors will also be considered. Other factors considered are more specific to the variable; for example, covariates in the analysis of red pine height growth would include bud size, seedling diameter, and total height of the seedling prior to the current season's growth in addition to ambient factors. Analyses will be conducted to determine which of these are both statistically significant as well as biological meaningful with out violating the necessary assumptions required for the analysis of covariance (Cochran 1957). The most general and encompassing ANOVA table to the project is shown in Table I.3. More detailed ANOVA tables can be found in each work element section of this report.

WORK ELEMENTS

As stated earlier, the various work elements of this project were established to group similar tasks and analyses. Although data from several work elements are often used to

Table I.2. Measurements needed to test the critical hypotheses of the ELF environmental monitoring program Upland Flora project, the objective it is related to, and the work elements addressing the necessary measurements and analyses.

Hypothesis Number	Related Objectives	Measurements	Work Elements
I	1,2	Weekly dendrometer band readings* climatic variables, soil nutrients, tree and stand characteristics.	1,2,3
II	1	Annual diameter bud growth, terminal bud size, plant moisture stress, microsite climatic variables, number of mycorrhizae.	1,2,3,5
III	1,2	Weekly height growth, annual height growth, terminal bud size, plant moisture stress, number of mycorrhizae, ambient measures.	1,2,3,5
IV	2	Periodic measures of plant dimensional variables including leaf size and phenological stages of flowering, fruiting, etc., climatic variables.	1,3
V	2	Bi-weekly sporocarp counts by species, climatic variables	1,4
VI	3	Monthly counts of mycorrhizal root tips by type, climatic variables, tree variables.	1,5
VII	5	Periodic collections of litter, nutrient analyses, climatical variables.	1,6
VIII	4	Periodic collections of foliage, nutrient analyses, climatic variables.	1,6
IX	6	Monthly inventory of red pine mortality caused by Armillaria root disease, soil texture, bulk density and rock content; hardwood stump characteristics and density.	2

*Italicized print designated the response variable; others listed are covariates.

test a single hypothesis, we have retained the work element format in this report to allow the reader to easily refer to details presented in past annual reports. Each of the following sections presents a synopsis of the rationale for study, measures and analyses, and progress.

Element 1: AMBIENT MONITORING

The growth and development of a forest community or an individual in the community is directly related to all the environmental factors (natural and anthropogenic) which influence the physical space the community or individual occupies. Any study which attempts to relate the development of a population to any one of these factors must also determine and screen out the effects of other independent factors. Thus, variability in plant growth, development, or phenological events within the influence of the ELF antenna system must first be related to microclimatic and other ambient variables before the effect of a single and potentially subtle factor, such as the electromagnetic fields of the ELF antenna, (National Research Council, 1977), can be quantified.

Given the overall importance of ambient factors to the Upland Tree and Herbaceous Project, the objectives of this monitoring work element are to:

1. evaluate the natural ambient differences between the control site and the test sites.

2. evaluate the natural annual ambient changes of a site over time to determine differences between pre-operational and operational time periods.

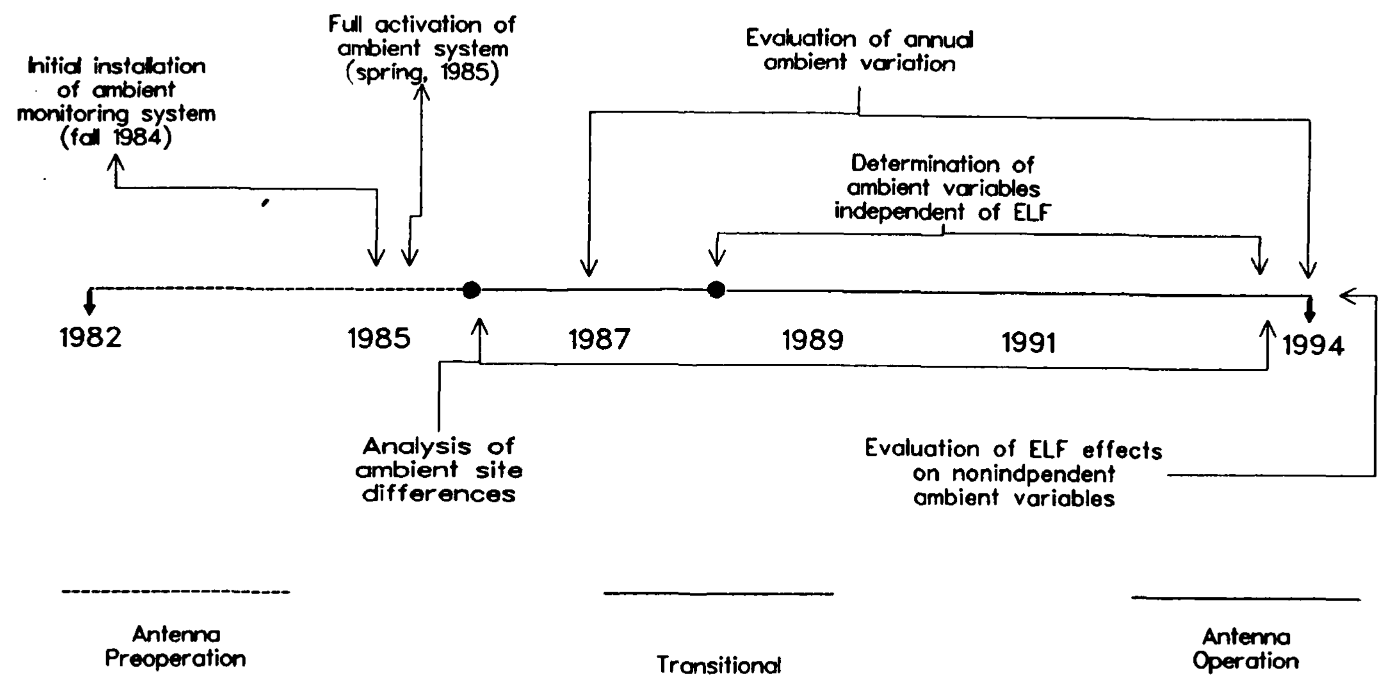
3. select ambient variables which are independent of ELF system effects. These variables will then be included in a database which can be used to (1) build models to predict community growth and development and (2) supply ambient variables as covariates for community growth and development analysis.

4. evaluate possible ELF system effects on non-independent ambient variables detected through the screening process in objective 3.

Accomplishing the first two objectives will not only document ambient differences among sites and annual changes in these conditions but also indicate ambient variables which will be potential candidates for growth and development modeling in the various study elements. An adequate database of ambient measurements will insure a proper analysis of climatic and soil relationships to other study components as discussed in the design section dealing with covariate analysis. Accomplishing the last objective will give direct measurement of any ELF system influences on such factors as solar radiation in the understory or soil nutrient status that may be affected by overstory biomass. The initiation and schedule of each phase of the objectives are presented in Figure 1.1.

Work on the Herbaceous Plant Growth and Tree Studies during the past two years has indicated that soil and possibly

Figure 1.1 Schedule and initiation of ambient monitoring objectives.



precipitation chemistry is important to the projects growth modeling efforts. Thus an increased emphasis has been placed on the collection and analysis of these variables. As a result of the increased work efforts associated with soil and precipitation chemistry this year the ambient monitoring element is separated into two sections: climatic monitoring and nutrient monitoring.

Climatic Monitoring

Sampling and Data Collection

System Configuration

The climatic variables being measured in the study are air temperature (30 cm and 2m above the ground), soil temperature and soil moisture at depths of 5 and 10 cm, global solar radiation, relative humidity, photosynthetically active radiation (PAR), and precipitation. The configuration and placement of the sensors at the study site has been presented in Appendix B (Table 1) of the 1985 Herbaceous Plant Growth and Tree Studies Project annual report.

Because of the location of individual sensors, air temperature (2 meters above the ground) in the plantation, precipitation, relative humidity, and global solar radiation are considered to be independent of possible ecological changes caused by ELF electromagnetic fields. Air temperature at the hardwood stands, soil temperature, soil moisture, air temperature (30 cm above the ground), and PAR (30 cm above the ground) may be more sensitive to ecological changes controlled by stand characteristics.

Air temperature, soil temperature, PAR, and relative humidity are measured every 30 minutes by a Handar, Inc. ambient monitoring platform. Global solar radiation is measured every 60 minutes, soil moisture is sampled every 3 hours, and precipitation monitored continuously. A microprocessor on board the ambient system calculates three hour averages or totals for the appropriate climatic variables. These averages and totals as well as the soil moisture and global solar radiation measurements are transmitted to the GOES East satellite every three hours and relayed to Camp Springs, Virginia. The data are transferred from Camp Springs to an IBM PC at MTU nightly.

Soil moisture subsampling procedures are performed at each site in order to more accurately measure soil moisture over the entire area of each plot. Twelve to fifteen cores are randomly taken from each plot at each site once a month. Moisture content for each depth (5 cm and 10 cm) is determined gravimetrically from a composite of the cores from a plot. These moisture contents are considered to represent the

average moisture content for a given plot for the day of core sampling.

Differences between the soil moisture calculated from the cores and readings from the soil moisture sensors for a given plot and day of core collection are used as an adjustment for the soil moisture readings for each plot over a monthly time interval. To eliminate any abrupt changes in soil moisture between consecutive months which would be attributed to the monthly adjustment, the weighting equation (1.1) is used to determine the actual monthly soil moisture sensor adjustments. The equation's adjustments for a given month are weighted more heavily to the month of adjustment.

Equation 1.1 Monthly adjustment for a specific plot

$$\frac{(CSM_{(M-1)}-PSM_{(M-1)})+2*(CSM_{(M)}-PSM_{(M)})+(CSM_{(M+1)}-PSM_{(M+1)})}{4}$$

CSM = Core Soil Moisture from the plot **M** = Month of Adjustment **M+1** = Following Month

PSM = Probe Soil Moisture from the plot **M-1** = Previous Month

In order to determine the accuracy of this adjustment procedure, an experiment was performed in August. As usual twelve cores were sampled from each plot, composited, weighed, and then dried at 105°C to determine soil moisture content. Another set of 12 cores were taken at each plot on the same day and cores were paired to give six composited samples from each plot for analysis. Soil moisture was gravimetrically determined for these composited sample pairs. Average soil moisture and standard deviations were computed for each group of samples. The average soil moisture from the six sets of samples from each plot were compared to the soil moisture determined from the original composited 12 core samples for a given plot. Differences and absolute differences (12 core composites-6 sets (2 core composites)) were calculated for each plot. The sample size needed to estimate average plot moisture with a 10% confidence interval at p=.10 was also determined. Table (1.1) presents these results as averages of each parameter for a site, stand type, and depth combination.

As can be seen in Table 1.1 our current sampling size is not adequate for our desired accuracy levels. It is planned to increase our sample size to 18 next year. This sample size should give the desired accuracy levels for all sites except the ground. Given a sample size of 18 the confidence interval for the ground site will be between 13 and 14 percent of the mean (p=0.10). Although a larger sample size would seem to be appropriate for this site, it is not practical in terms of site degradation due to sampling and manpower resources to increase the number of samples taken at the ground site.

Table 1.1. Comparison of soil moisture sampling size.

Site	Stand[1/] Type	Depth (cm)	Average Plot Soil Moisture % 2 cc	St. Dev. % 2 cc	Soil Moisture % 12cc	Dif. 12 cc-2 cc	Absolute Dif. 12 cc-2 cc	Average #[2/] of Samples
Ground	P	5	11.0	3.44	12.3	1.3	1.3	43
		10	12.6	4.39	13.2	.6	.6	56
Antenna	P	5	8.2	1.55	9.4	1.2	1.2	16
		10	8.8	1.78	10.8	2.1	2.1	18
Antenna	H	5	9.7	1.82	9.0	-.7	.7	15
		10	10.7	1.91	9.9	-.7	.7	16
Control	P	5	17.1	2.17	17.5	.5	.6	8
		10	17.1	2.26	18.2	1.1	1.1	[illegible]
Control	H	5	11.9	1.98	12.2	.3	.4	12
		10	13.4	3.10	13.3	-.1	1.0	22

2 cc = 2 core composite
12 cc = 12 core composite

1/ H=Hardwood
P=Plantation
2/ p=0.10

As stated in the 1986 Herbaceous Plant Cover and Tree Studies Annual Report, 1985 soil moisture measurements could not be used in any analyses. Thus the 1987 measurements were only the second full year of soil moisture measurement.

System Maintenance and Performance

The performance of the climatic monitoring system in 1987 was hampered by a lightning strike at the control site in May and the ground site in July. After the fist lightning strike in May the control platform was returned to the manufacturer for repairs and replaced with the ground platform. A Omnidata Polycorder with analog capabilities was used at the ground to collect temperature and solar radiation measurements during the time of platform repair. The Omnidata Polycoder was also damaged by lightning in early July. Repair to the Handar platform was completed in the end of July. All systems were operational at this time. Downtime for the control platform was 7 days and for the ground platform 34 days due to lightning strikes. Downtime of the soil moisture sensors was longer then the general ground platform downtime due to the limited capability of the Omnidata Polycorder to transmit 12 volt excitation signals.

Beginning in 1988 a cooperative effort between IITRI and project personnel will be initiated to developed hardware to protect the system (sensors and processor) from lightning strikes. The modifications to the system should be completed by the start of the 1988 growing season. These modifications will eliminate downtime and missing data replacement which currently takes place.

Data Management

Daily averages or totals, maximums, and minimums are computed for each sensor using all 3 hour measurements (eight/day) transmitted by the platforms. If less than six transmissions are received in a day for an air temperature, relative humidity, or solar radiation sensor daily statistics for that sensor are not calculated. Due to small diurnal variability in soil temperature and soil moisture the transmission limits for calculation of daily statistics for these sensors are four and two transmissions respectively. Weekly and monthly averages or totals are then computed from these summaries.

Weekly or seven day summaries comprise the basic climatic unit used by the tree productivity element. One summary generated from the climatic information is adjusted to correspond to the weekly measurements of tree diameter or height. For example if red pine height growth and hardwood tree diameter growth was determined for the seven days from May 9 through May 15, weekly ambient summaries are also calculated for these same seven days. This insures a

consistent relationship between tree productivity measurements and climatic measurement summaries. Weekly averages are considered missing and not calculated if less than four daily averages are computed from a sensor for a given seven day period. Daily climatic information is summarized in the same manner to correspond to sampling periods in each of the other project elements.

Monthly averages and totals are the basic unit used for site and year comparisons in this study element. Weekly averages and totals corresponding to seven day periods in a month are calculated from the daily climatic averages and totals (Table 1.2). These weeks are used as repeated replicate samples for each plot during each month during the growing season (refer to analysis section).

Table 1.2. Example of weekly units.

Date	Week
May 1-7	1
May 8-14	2
May 15-21	3
May 22-30	4

<u>Missing Data Replacement</u>

As the result of platform and sensor downtime in the past three years, daily climatic averages or totals are estimated for days in which specific ambient observations are missing. Four hierarchical criteria and methods are used to replace the missing data. The criteria are:

1) Daily averages missing from one or two plots from a stand type of an individual site are estimated using an average of the daily summaries from the functional plots on the same stand type and site.

2) Missing daily plot averages from adjacent sites (ground and antenna) are replaced by the stand type averages from the plantation on the adjacent site if 1) there are no significant differences between the two sites 2) there are no significant differences among plots within sites for the variable of interest. Only air temperature and precipitation have met these criteria on the ground and antenna site in the past three years

3) Missing daily plot averages from the ground or antenna site not estimated by the methods outline in criteria 2 are predicted using regression equations. These equations are fitted using observed data from the

sensor, plot, and site combination with the missing data as the dependent variable and the observed average daily plantation observation from the other adjacent site as the independent variable.

4) Missing plot daily average air temperatures, relative humidity, and total daily precipitation at the control site are estimated from regression equations fitted to individual observed plot averages or totals and daily observations at the Crystal Falls C#200601 weather station. This weather station is located within 9 km of the control site and is operated by the Michigan Department of Natural Resources in Crystal Falls. Missing average daily soil temperatures are estimated using regression equations fitted to stand type daily averages of air temperature at the site.

Using these techniques 95% of the missing daily averages or totals could be replaced. Regression equations used in the data replacement along with the related regression statistics for 1985-86 are presented in the 1986 Herbaceous Plant Cover and Tree Studies annual report and the 1987 equations are presented in Appendix A (Table 1-7) of this report.

Estimates of climatic measurements obtained from criteria 1-4 are used throughout the project. Coefficients of determination as well as confidence intervals for the equations are well within acceptable limits. It is felt that the missing data replacement methods give unbiased and accurate estimates of climatic measurements and thus the variables are used in the statistical analyses in the various elements.

Data Analysis

Comparisons of site and time differences of the ambient variables generally follow a split-plot in space and time experimental design. Last year the plot factor was removed from the design for ambient statistical analysis. As a result, detection limits associated with the analyses were relatively high. This year plot has been included in the design. Since plot location at one site is not related to plot location at another site, plots are nested within sites. This nesting gives a more sensitive test of main factor effects.

The design for this element also includes month of the year as another time factor. This factor along with its associated interactions (Table 1.3) determine: 1) if climatic changes occur during the year, 2) if the climatic relationships between sites are constant within a year, and 3) if climatic relationships between sites within the growing season are constant over the time period of the study. As mentioned in the data management section of the element, weekly summaries are the basic unit used in the element. We

Table 1.3. **General analysis of variance of Element 1.**

Source of Variation	Sum of Squares	Mean Square	F-Ratio
SI	$SS_{(S)}$	$MS_{(S)}$	$MS_{(S)}/MS(E_1)$
PL w SI (Error 1)	$SS(E_1)$	$MS(E_1)$	$MS(E_1)/MS(E_2)$
Wk w PL w SI (Error 2)	$SS(E_2)$	$MS(E_2)$	
YR	SS(Y)	MS(Y)	$MS(Y)/MS(E_3)$
YR x SI	SS(YS)	MS(YS)	$MS(YS)/MS(E_3)$
YR x PLwSI (Error 3)	$SS(E_3)$	$MS(E_3)$	$MS(E_3)/MS(E_4)$
YR x WKwPLwSI (Error 4)	$SS(E_4)$	$MS(E_4)$	
ST	SS(T)	MS(T)	$MS(T)/MS(E_5)$
ST x SI	SS(TS)	MS(ST)	$MS(ST)/MS(E_5)$
ST x PLwSI (Error 5)	$SS(E_5)$	$MS(E_5)$	$MS(E_5)/MS(E_6)$
ST x WKwPLwSI (Error 6)	$SS(E_6)$	$MS(E_6)$	
MO	SS(M)	MS(M)	$MS(M)/MS(E_7)$
MO x SI	SS(MS)	MS(MS)	$MS(M_5)/MS(E_7)$
MO x PLwSI (Error 7)	$SS(E_7)$	$MS(E_7)$	$MS(E_7)/MS(E_8)$
MO x WKwPLwSI (Error 8)	$SS(E_8)$	$MS(E_8)$	
YR x MO	SS(YM)	MS(YM)	$MS(YM)/MS(E_9)$
YR x MO x SL	SS(YMS)	MS(YMS)	$MS(YMS)/MS(E_9)$
YR x MO x PLwSI (Error 9)	$SS(E_9)$	$MS(E_9)$	$MS(E_9)/MS(E_{10})$
YR x MO x WKwPLwSI(Error 10)	$SS(E_{10})$	$MS(E_{10})$	
YR x ST	SS(YT)	MS(YT)	$MS(YT)/MS(E_{11})$
YR x ST x SI	SS(YTS)	MS(YTS)	$MS(YTS)/MS(E_{11})$
YR x ST x SI (Error 11)	$SS(E_{11})$	$MS(E_{11})$	$MS(E_{11})/MS(E_{12})$
YR x ST x SI x WkwPLwSI(Error 12)	$SS(E_{12})$		
ST x MO	SS(TM)	MS(TM)	$MS(TM)/MS(E_{13})$
ST x MO x SI	SS(TMS)	MS(TMS)	$MS(TMS)/MS(E_{13})$
ST x MO x PLwSI (Error 13)	$SS(E_{13})$	$MS(E_{13})$	$MS(E_{13})/MS(E_{14})$
ST x MO x WKwPLwSI (Error 14)	$SS(E_{14})$	$MS(E_{14})$	
YR x ST x MO x SI	SS(YTMS)	MS(YTMS)	$MS(YTMS)/MS(E_{15})$
YR x ST x MO x PLwSI (Error 15)	$SS(E_{15})$	$MS(E_{15})$	$MS(E_{15})/MS(E_{16})$
YR x ST x MO x WkwPlwSI (Error 16)		$SS(E_{16})$	$MS(E_{16})$

Site = SI, S Within=w
Stand Type = ST, T
Year = YR, Y
Month = MO, M
Plot = PL

consider these weeks as a repeated measure on a given climatic variable. Repeated measures are multiple observations on a specific experimental unit or (in the case of climatic measurements) a specific three dimensional area. Since the observations are made on the same unit they are not independent of each other. Therefore weeks are nested in plots in the design (Table 1.3).

Comparison of ambient variables among sites, years, months, etc. were made using analysis of variance test. Differences between specific months, years, sites, etc. were made using the Student-Newmen-Keuls (SNK) multiple range test if tests with analysis of variance showed significant differences for the appropriate factor. Detection limits for each variable were also calculated using this multiple range test. In cases where an adequate number of replicates were not available for analysis of variance testing, paired t-tests were used to test factor differences. All factors were tested at the 0.05 probability level

Progress

This year concludes the third full year of data collection by the ambient monitoring system. It was also year was the first year of low level operation of the ELF antenna. Thus comparisons of sites, years, and site by year interactions will be presented and related to possible detection of ELF effects on climatic variables. The power or detection limits associated with these tests will also be presented for each climatic variable.

Air Temperature (2m above the ground)

Air temperature has a substantial influence on plant physiological processes such as photosynthesis, cell division, and elongation, chlorophyll synthesis, and enzymatic activity (Kramer and Kozlowski 1979). For any individual species given a specific period during the growing season, optimal net photosynthesis is associated with a specific range of temperatures (Waring and Schlesinger 1985). Thus differences in air temperature between the control and test sites or among study years could have significant effects on vegetation growth and development.

Site Comparisons: Monthly average air temperature for the three sites for each year are presented in Appendix A (Table 8, Table 10, Table 12). As shown in Figures 1.2-1.4 air temperature at the control site is consistently warmer than at the test sites regardless which stand type is being compared. Average temperature during the growing season over the three year study period was .6°C and .7°C warmer at the

Figure 1.2

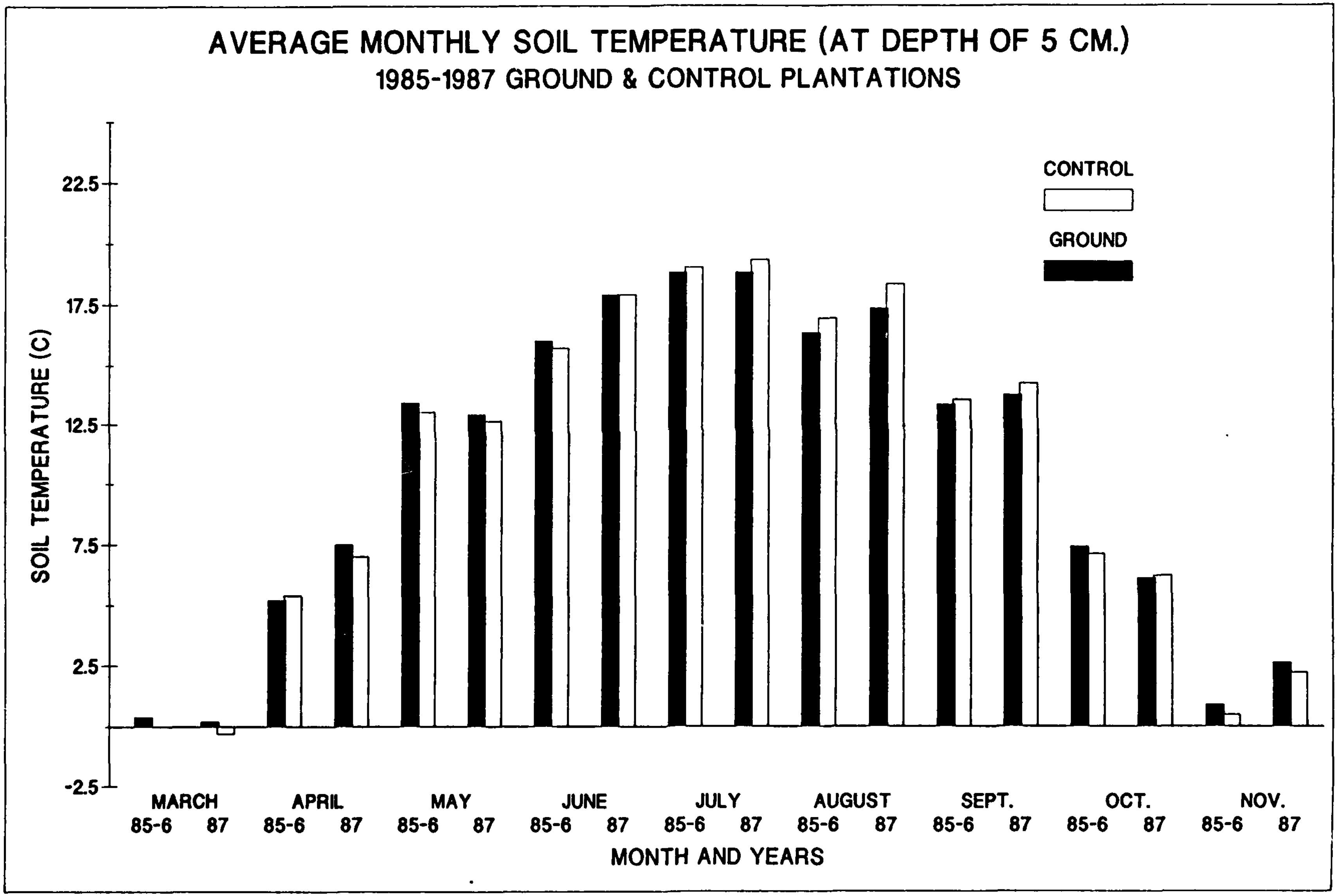

AVERAGE MONTHLY SOIL TEMPERATURE (AT DEPTH OF 5 CM.)
1985-1987 GROUND & CONTROL PLANTATIONS
CONTROL
GROUND
SOIL TEMPERATURE (C)
22.5
17.5
12.5
7.5
2.5
-2.5
MARCH 85-6 87
APRIL 85-6 87
MAY 85-6 87
JUNE 85-6 87
JULY 85-6 87
AUGUST 85-6 87
SEPT. 85-6 87
OCT. 85-6 87
NOV. 85-6 87
MONTH AND YEARS

Figure 1.3

AVERAGE MONTHLY AIR TEMPERATURE
(TWO METERS ABOVE THE GROUND)
1985-87 CONTROL AND ANTENNA PLANTATION

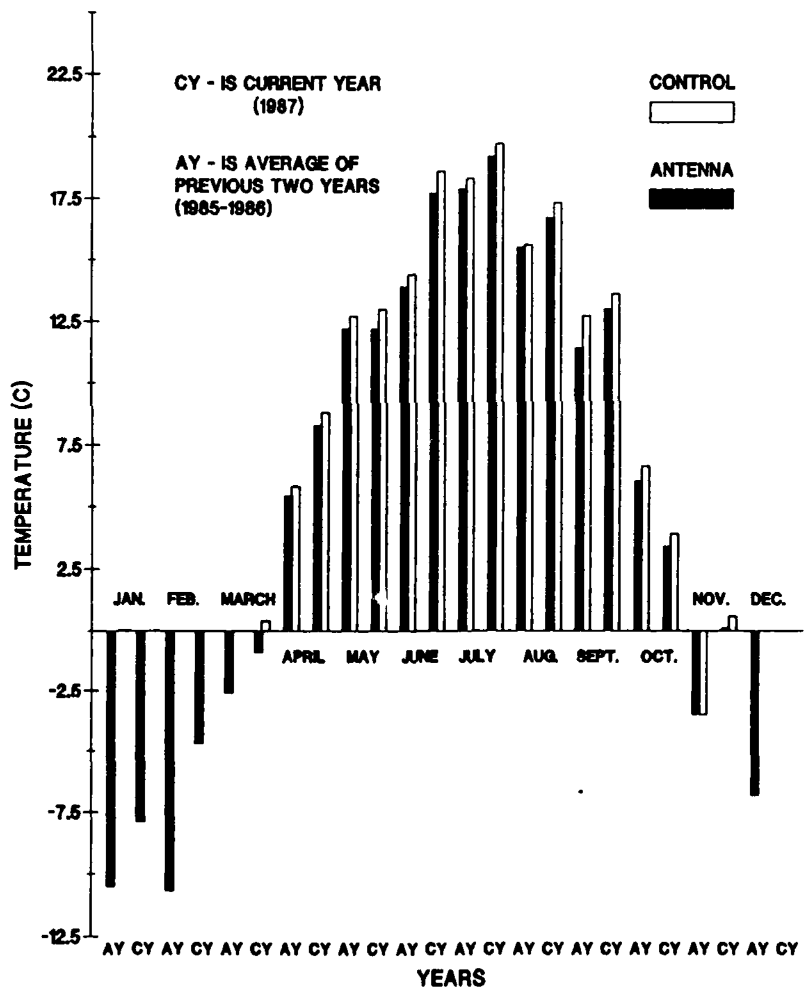


Figure 1.4

AVERAGE MONTHLY AIR TEMPERATURE
(TWO METERS ABOVE THE GROUND)
1985-87 CONTROL AND ANTENNA HARDWOOD STANDS

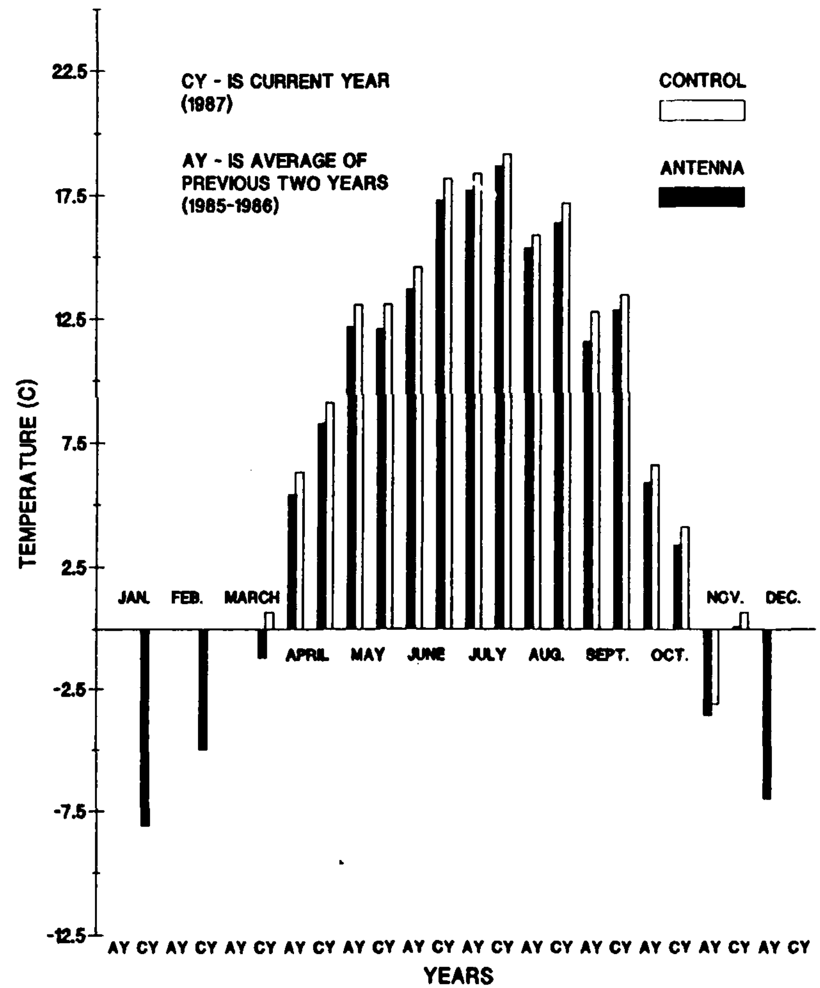


Table 1.4. Comparisons of air temperature (2 m above ground) during the 1985-1987 growing seasons.

	Stand Type							
	Plantation				Hardwood			
	1985	1986	1987	$\bar{X}$	1985	1986	1987	$\bar{X}$
Control	11.9	12.5	13.6	12.7	12.3	12.9	13.5	12.9
Antenna	11.5	12.1	12.9	12.1	11.4	12.0	12.7	12.0
Ground	11.4	12.0	12.7	12.0				
Control-Antenna	.4	.4	.7	.6	.9	.9	.8	.9
Control-Ground	.5	.5	.9	.7				

Average Air Temperature (Site)

Control 12.9 a[1/]	Antenna 12.1 b
Control 12.7 a	Ground 12.0 b

Average Soil Temperature (Year)

Control & Antenna			Control & Ground		
1985	1986	1987	1985	1986	1987
11.8 a	12.4 b	13.1 c	11.7 a	12.3 b	13.1 c

[1/]Sites or years comparisons with the same letters for specific site combinations are not significantly different (p=0.05).

All values expressed in °C

control site plantation than at the antenna and ground plantations respectively (Table 1.4). Average temperature at the control hardwood stand was .9^{o}C warmer than at the antenna hardwood stand. ANOVA tests show significant differences between the control and ground sites (p=0.004) as well as the control and antenna sites (p=0.001).

Annual Comparisons: Air temperatures in 1987 were warmer than in all preceding years for all sites and stand types (Table 1.4). ANOVA tests show significant differences among years (p<.001) for both the control antenna and control ground comparisons. Multiple range tests (p=0.05) rank annual air temperature for both comparisons as follows: 1987>1986>1985.

Site by Year Comparisons: Relationships of air temperature between the control and test sites appear to be relatively stable from one year to the next. Site by year interactions were not significantly different for either the control vs. antenna (p=0.891) combination or the control vs. ground (p=0.452) combination. Site by year by stand type interactions were also not significant (p=0.858).

Detection Limits and Summary: Detection limits associated with each of the factors (Table 1.5) were well

Table 1.5. Detection limits (p=.05) associated with year and site factors for air temperature (2 m above ground.

Factor	Detection Limit ^{o}C	% Mean
Site (Control vs Ground)		
Site	.40	3.21
Year	.24	1.93
Site x Year	.35	2.81
Site (Control vs Antenna)		
Site	.23	1.84
Year	.13	1.04
Site x Year	.19	1.52
Site x Stand Type	.33	2.64
Site x Stand Type x Year	.24	1.92

within acceptable limits. The detection limits associated with these factors were much higher in previous years analyses. The improvement in the current analysis can be contributed to the use of plots nested within site in the design.

As stated previously site and year differences were significant at p=0.05 for each of the site comparisons. However, no significant site by year interactions were found. This implies that although there are actual air temperature differences between sites and year, differences between sites over the study period have remained stable. As stated in the introduction air temperature in the hardwood stands could be more sensitive to ELF effects than air temperature in the plantations. This was not apparent since ANOVA tests showed no significant site by stand type by year interactions (p=0.891) for the control vs antenna comparisons. Thus there is no evidence that the present level of ELF electromagnetic exposure has effected air temperature at the test sites.

Soil Temperature

Soil temperature like air temperature has a direct influence on plant physiological process such as cell division and elongation. However soil temperature also indirectly influences plant growth by effecting permeability of roots and thus water uptake (Kramer 1983), biological decomposition and availability of nutrients (Brady 1974). Climatic conditions such as insolation, air temperature, and precipitation as well as soil characteristic are the main factors controlling soil temperatures. Thus possible changes in vegetation or soil properties (organic matter content etc.) due to ELF antenna operation could have a major effect on soil temperature. These effects would appear to be more dramatic in the hardwood stands where microclimate is influenced to greater degree by vegetation than it is in the younger plantation stands.

Soil Temperature (depth of 5cm)

Site comparisons: Average soil temperatures at depths of 5cm at the control and ground plantations were within .2^{o}C during the study period (Table 1.6). Average soil temperature during the growing season was consistently warmer at the antenna plantation than at the control plantation in 1985 through 1987. However soil temperatures were warmer at control hardwood stand than at the antenna hardwood stand (Table 1.6).

ANOVA tests showed no significant differences in soil temperature (5cm) between the control and ground site (p=0.692) or the control and antenna sites (p=0.431). Differences between sites are more apparent when soil temperatures were compared for each individual month of the growing season. Soil temperature (5cm) tends to warm in the

Table 1.6. Comparison of soil temperature (5cm) during the 1985-1987 growing seasons.

	Stand Type							
	Plantation				Hardwood			
	1985	1986	1987	$\bar{X}$	1985	1986	1987	$\bar{X}$
Control	12.5	13.5	13.6	13.2	10.9	11.7	12.3	11.6
Antenna	12.9	13.5	13.7	13.4	10.1	11.2	11.8	11.1
Ground	12.5	13.3	13.5	13.1				
Control-Antenna				-.2				.5
Control-Ground				.1				

Average Soil Temperature (5cm)
(Site)

Control	Antenna
12.4 a[1/]	12.2 a

Control	Ground
13.1 a	13.1 a

Average Soil Temperature (5cm)
(Year)

Control & Antenna			Control & Ground		
1985	1986	1987	1985	1986	1987
11.6 a	12.4 b	12.8 c	12.5 a	13.4 b	13.6 b

[1/]Sites or years with the same letters for specific site combinations are not significantly different (p=.05).

All values expressed in ^{o}C

spring months (April, June, and July) and cool in the late summer (August and September) more rapidly at the test plantations sites than at the control plantation sites (Figure 1.5, Figure 1.7). Although not as apparent as in the plantation stand type, this phenomenon occurs in the hardwood stands as well (ie. differences between control and antenna sites are greatest in August and September and least in April and May, Figure 1.6).

Annual Comparisons: Average soil temperature at 5cm was significantly warmer in 1986 than in 1985 for all site comparisons. Only the control and antenna site comparison produced significant differences between 1987 and 1986. For all sites and stand types average soil temperatures (5cm) were higher in 1987 than 1986 and higher in 1986 than 1985 (Table 1.6).

Site by Year Comparisons: Site and year interactions were not significant for the control vs antenna site comparison (p=0.978) or the control vs ground site comparison (p=0.828). This suggests that average soil temperature (5cm) for a given site and year can be adequately explained by site and year factors alone. Year by stand type by site interactions were also not significantly different (p=0.581). Thus changes in soil temperature at sites from one year to the next is relatively the same between the stand types.

Detection limits and summary: Except for site and stand type interactions, detection limits associated with soil temperature (5cm) were below 5.0% (Table 1.7). The detection

Table 1.7. Detection limits (p=.05) associated with year and site factors for soil temperature (5cm).

Factor	Detection Limit °C	% Mean
Site (Control vs Ground)		
Site	.24	1.83
Year	.37	2.82
Site x Year	.52	3.97
Site (Control vs Antenna)		
Site	.57	4.64
Year	.30	2.44
Site x Year	.42	3.42
Site x Stand Type	.93	7.57
Site x Stand Type x Year	.59	4.80

Figure 1.5

AVERAGE MONTHLY SOIL TEMPERATURE
(AT A DEPTH OF 5 CM.)
1985-87 CONTROL AND ANTENNA PLANTATIONS

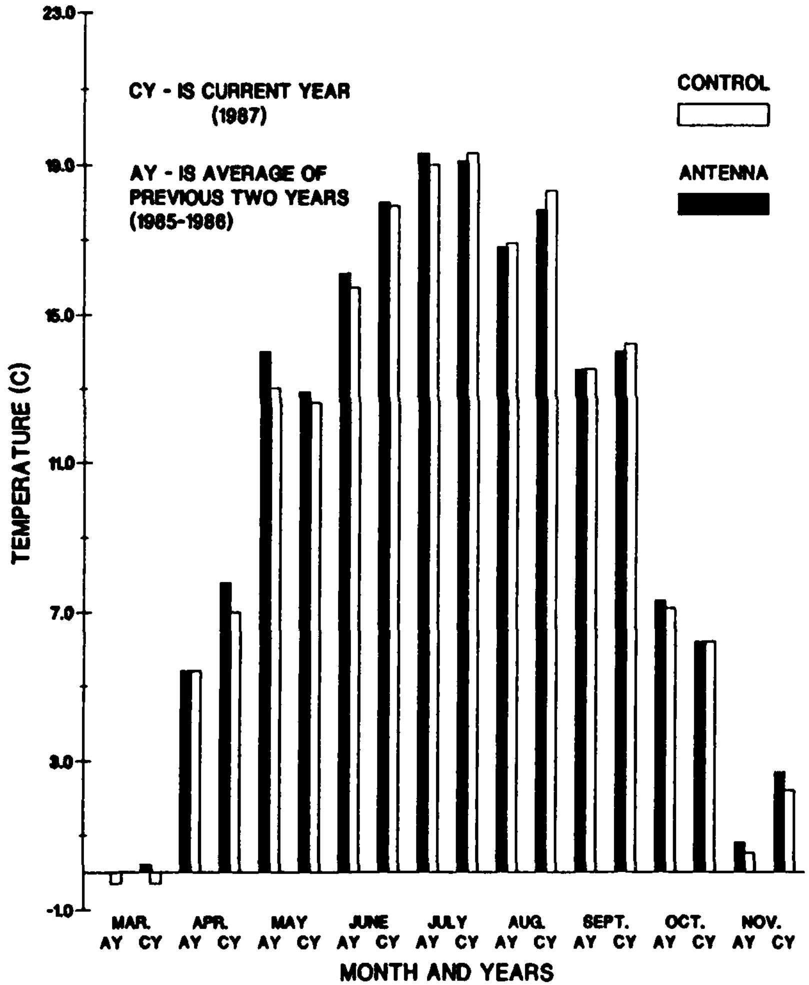


Figure 1.6

AVERAGE MONTHLY SOIL TEMPERATURE
(AT A DEPTH OF 5 CM.)
1985-87 CONTROL AND ANTENNA HARDWOOD STANDS

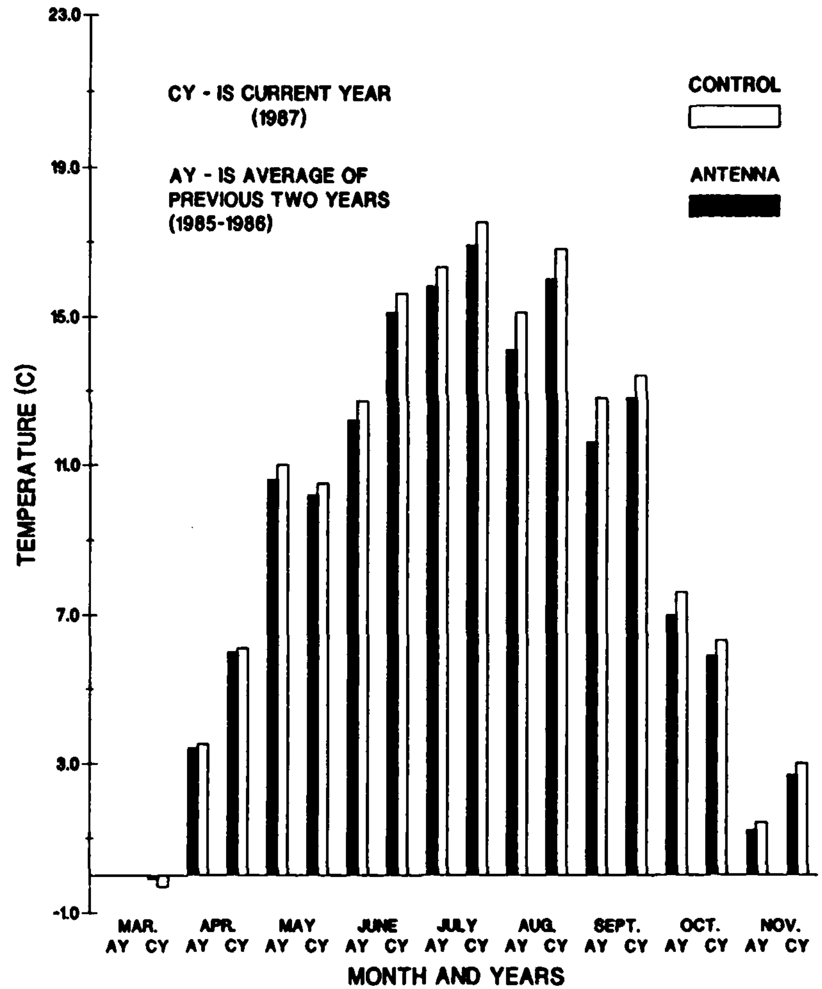
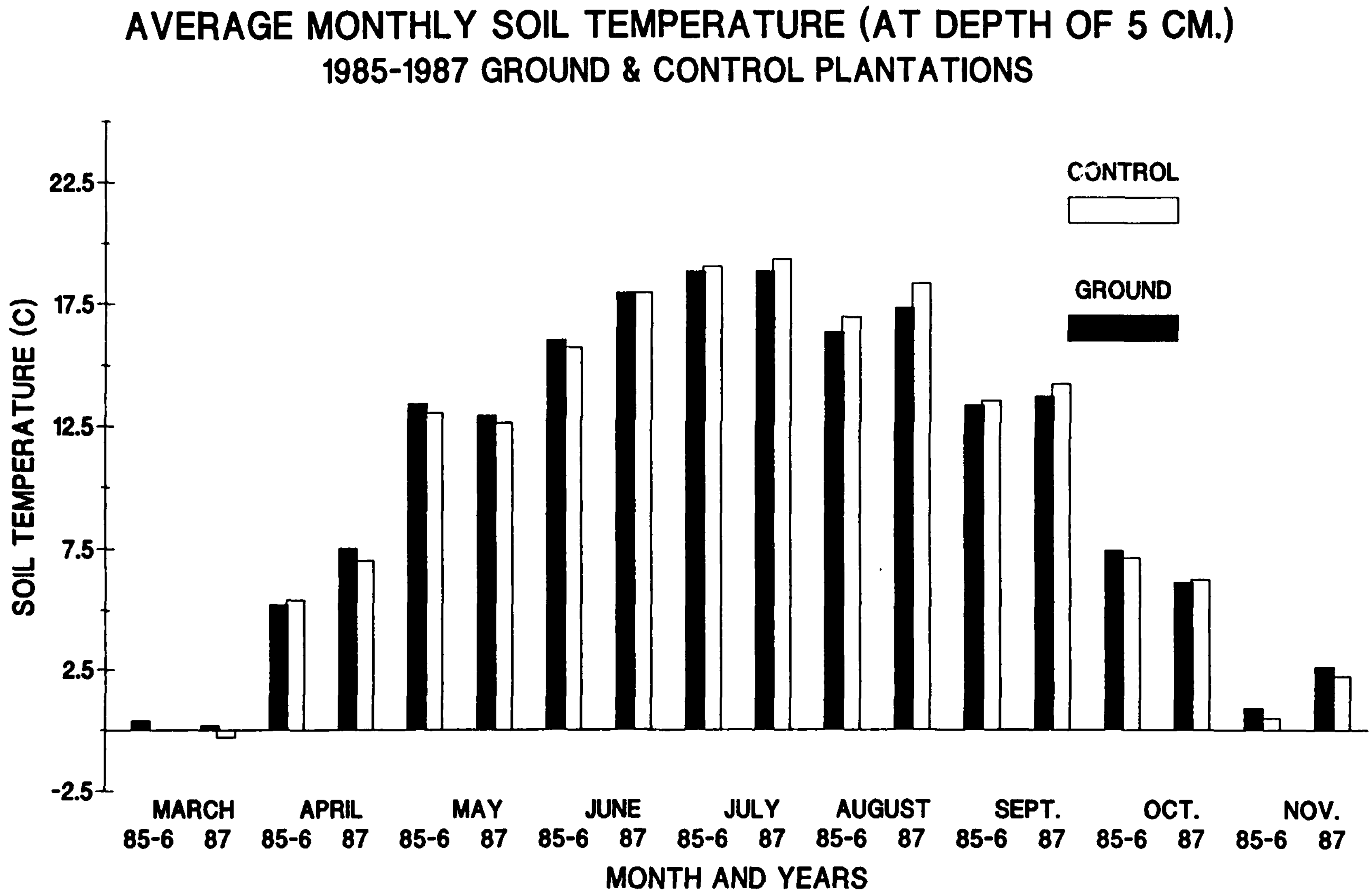


Figure 1.7


AVERAGE MONTHLY SOIL TEMPERATURE (AT DEPTH OF 5 CM.)
1985-1987 GROUND & CONTROL PLANTATIONS
SOIL TEMPERATURE (C)
22.5
17.5
12.5
7.5
2.5
-2.5
CONTROL
GROUND
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPT.
OCT.
NOV.
85-6
87
MONTH AND YEARS

limit for this factor (site by stand type) was 7.57%. Detection limits were lower this year than last due to the statistical design employed.

This year's comparisons indicate that the present level of ELF exposure has not affected soil temperature at depths of 5cm. This conclusion is based on: 1) differences between sites were not different at p=0.05, 2) although differences between years were significant, site by year interactions were not significantly different, and 3) site by stand type by year interactions were not different. These factors suggest that soil temperature relationships between the control and test sites as well as stand types have remained stable over the study period , and effects of the ELF field has not changed this relationship.

Soil Temperature (depth 10cm)

Site Comparisons: Average soil temperature at the control site was .1^{o}C warmer than both the antenna and ground sites respectively (Table 1.8). Comparisons of the sites using ANOVA tests showed no significant differences between the control and antenna sites (p=0.437) or the control and ground sites.

Annual Comparisons: ANOVA tests indicated significant differences among years for all site comparisons (control vs ground p<0.001 and control vs antenna p<0.001). Multiple range tests (p=0.05)rank the annual soil temperature (10 cm) in the following order: 1985<1986<1987 (Table 1.8).

Site by Year Comparisons: No significant differences were found for site by year interactions for the control vs antenna (p=0.400) or control vs ground comparisons (p=0.697). However, differences between sites during the study period were more apparent when stand types are considered separately. Table 1.8 shows that average soil temperature (10cm) was .6^{o}C warmer at the control hardwood stand than at the antenna hardwood stand type during 1985 and 1986. However,in 1987 the control hardwood stand was .2^{o}C cooler than the antenna hardwood stand. These changes in 1987 can be attributed to soil temperature (10 cm) in the antenna hardwood stand being warmer than the control during the months of April through July (Figure 1.10). Although these trends were evident in the hardwood stands, no such trends were apparent in the plantation comparisons (Figure 1.8-1.9). Furthermore these trends were not evident in the hardwood stand comparisons of soil temperature at a depth of 5cm. ANOVA tests showed no significant differences (p=0.085) for the control vs antenna site by stand type by year interactions. However the probability (p=0.085) associated with this interaction for

Table 1.8. Comparisons of soil temperature (10cm) during the 1985-1987 growing seasons.

	Stand Type							
	Plantation				Hardwood			
	1985	1986	1987	$\bar{X}$	1985	1986	1987	$\bar{X}$
Control	12.4	13.3	13.6	12.9	10.8	11.5	11.5	11.3
Antenna	12.6	13.4	13.6	13.2	10.2	10.9	11.7	10.9
Ground	12.2	13.0	13.2	12.8				
Control-Antenna	- .2	- .3	.0	- .2	.6	.6	- .2	.4
Control-Ground	.2	.1	.4	.2				

Average Soil Temperature (10cm)
(Site)

Control	Antenna
12.2 a[1/]	12.1 a
Control	**Ground**
12.9 a	12.8 a

Average Soil Temperature (10cm)
(Year)

Control & Antenna			Control & Ground		
1985	1986	1987	1985	1986	1987
11.5 a	12.3 b	12.6 c	12.3 a	13.1 b	13.4 c

1/ Sites or years with the same letters for specific site combinations are not significantly different (p=.05)

All values expressed in ^{o}C

Figure 1.8

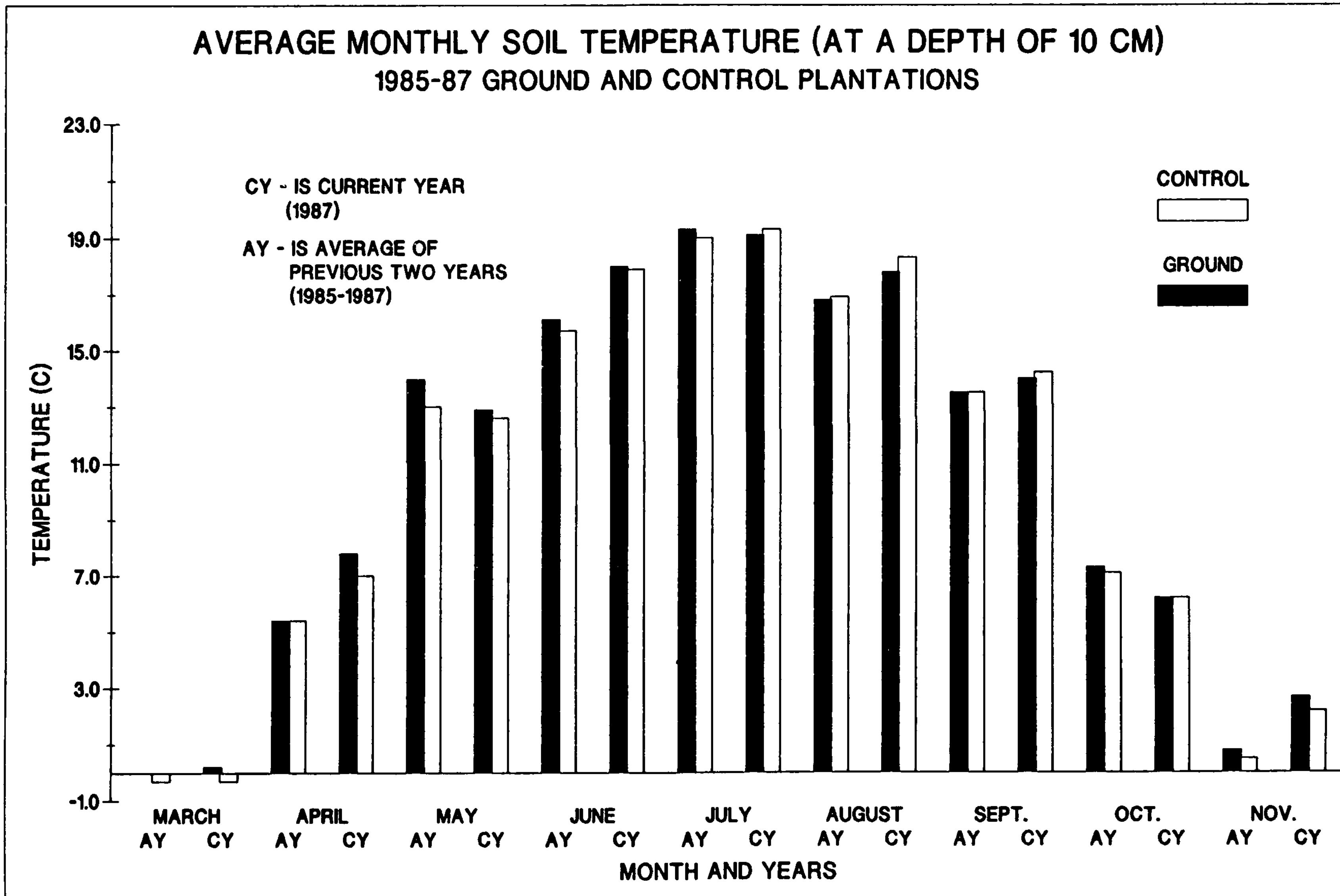

AVERAGE MONTHLY SOIL TEMPERATURE (AT A DEPTH OF 10 CM)
1985-87 GROUND AND CONTROL PLANTATIONS
CY - IS CURRENT YEAR (1987)
AY - IS AVERAGE OF PREVIOUS TWO YEARS (1985-1987)
CONTROL
GROUND
TEMPERATURE (C)
23.0
19.0
15.0
11.0
7.0
3.0
-1.0
MARCH AY CY
APRIL AY CY
MAY AY CY
JUNE AY CY
JULY AY CY
AUGUST AY CY
SEPT. AY CY
OCT. AY CY
NOV. AY CY
MONTH AND YEARS

Figure 1.9

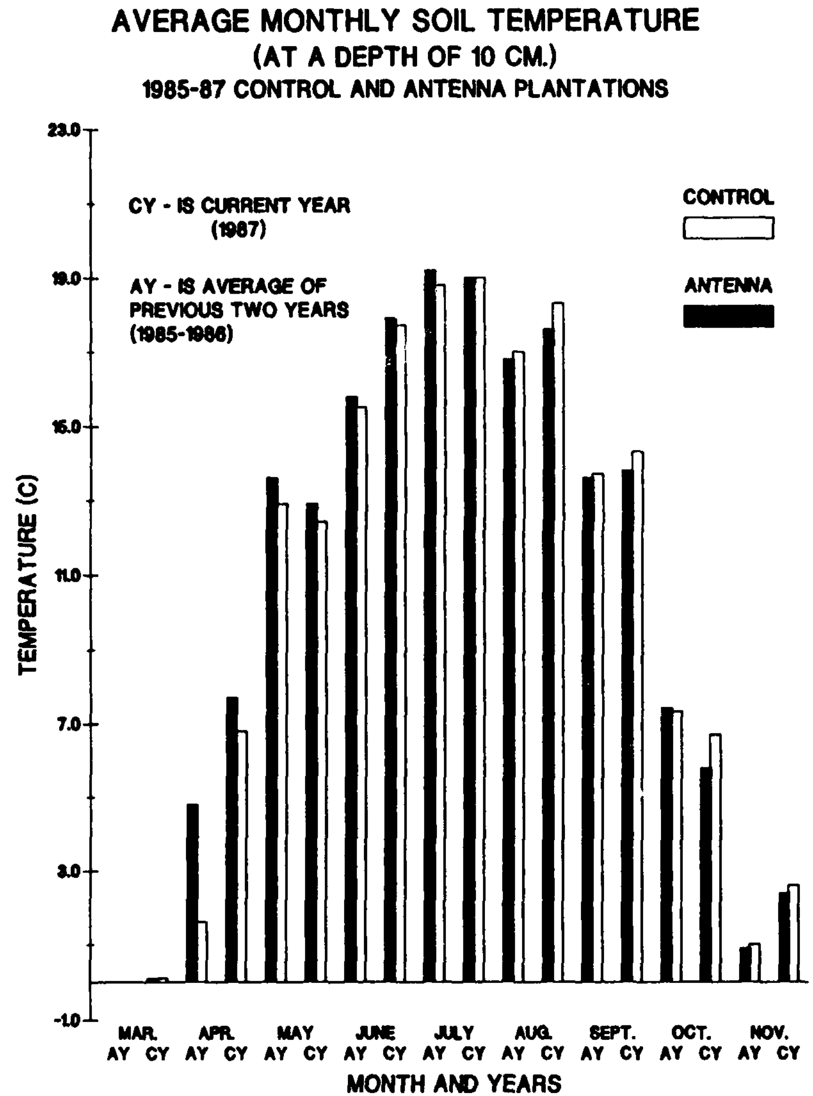
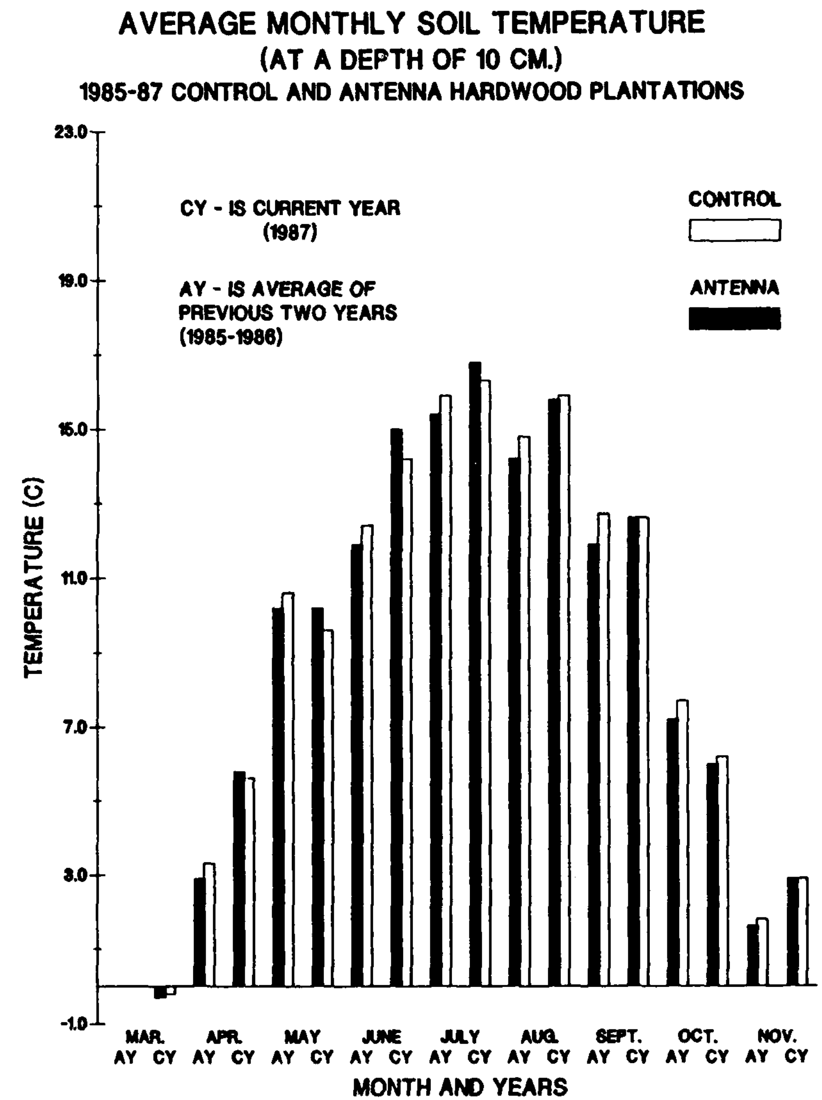


Figure 1.10



soil temperature (10 cm) was lower than for any other temperature variable.

Detection Limits and Summary: Detection limits for all factors were below 7.0% (Table 1.9). The factors which have the lowest detection limits were site, year, and site by year interactions.

No significant differences were found for site, year, and site by year interactions (p=.05). However the site by stand type by year interaction while not being significant at p=0.05 was significant(p=0.085) at p=0.10. Comparisons of means showed that in 1985 through 1986 the antenna hardwood stand was cooler than the control. In 1987 (when the ELF antenna was operational) the antenna stand was warmer than the control. Thus it would be imprudent to conclude that present level of ELF has not affected soil temperature at 10cm at the test sites.

Table 1.9. Detection limits (p=.05) associate with year and site factors for soil temperature (10 cm).

Factor	Detection Limit °C	% Mean
Site (Control vs Ground)		
Site	.41	3.17
Year	.30	2.32
Site x Year	.42	3.25
Site (Control vs Antenna)		
Site	.25	2.22
Year	.27	2.39
Site x Year	.39	3.46
Site x Stand Type	.73	6.48
Site x Stand Type x Year	.67	5.94

Soil Moisture

The amount and availability of water is a key factor in determining forest site productivity. The importance of water to plant growth should not be underestimated since almost all plant processes are influenced by the supply of water (Kramer 1983). Water in the soil is the primary media for transportation o: nutrients within plants and is a reagent in photosynthesis. Apical and radial growth of trees have been shown to be highly correlated to soil water supplies (Zahner 1968).

This year soil moisture tension has been analyzed to more fully investigate moisture relationships among the sites. Although moisture content gives a valuable measurement of the amount of water contained in the soil, it does not reflect to what degree plants can utilize this water. The tension at which the soil holds the water determines in a large part to what degree a plant can absorb water.

Given a specific moisture content, the availability of water can vary depending on soil characteristics. Thus tension may give a more sensitive estimate of site and year comparisons among the study sites. Tension values were estimated from equations relating soil moisture content at each plot to soil moisture tension (Appendix C). These equations were applied to daily average soil moisture content at each depth at each plot.

Soil Moisture (depth 5cm)

Site Comparisons: Average soil moisture content (5cm) at the control site was higher than at the two test sites (Table 1.10). However, these differences were only significant for the control vs antenna comparison (p=.002). ANOVA tests also indicated that site by treatment interactions were also significant (p=0.024). Multiple range tests showed that soil moisture content was significantly greater at the control hardwood stand than at the antenna hardwood stand. This relationship was not evident for the plantation stand type. This may be in part due to the differences in tree species, ages, or density levels of the two stand types (hardwood and plantation).

When soil moisture tension is used to compare sites, the control was found to have the lowest tension in the plantation stand type and highest tension in the hardwood stand type (Table 1.10),but no significant differences (p=0.05) were found between the control site and the two test sites. Furthermore site by stand type interactions were also not found to be significantly different for the control and antenna site comparisons (p=.222).

For both types of soil moisture measurements, content and tension, tests on the plot within site factor (error term for the site factor) were found to be significant. This suggest that differences among plots within a site are larger than differences among sites. This is not totally surprising since soil moisture can vary with small changes in soil characteristics.

Annual Comparisons: Differences between 1986 and 1987 measurements of soil moisture content or soil moisture tension were not significant at p=0.05. As with site comparisons all but the control vs antenna comparison had significant year by plot within site interactions (error term for year factors). This again indicates a large variability within sites. This

Table 1.10. Comparisons of soil moisture content (5cm) and soil moisture tension (5 cm) during the 1985-1987 growing season.

Soil Moisture Content (5 cm) %

	Plantation Stand Type			Hardwood Stand Type		
	1986	1987	$\bar{X}$	1986	1987	$\bar{X}$
Control	16.0	13.5	14.7	14.1	10.9	12.5
Antenna	9.2	11.3	10.2	10.4	10.8	10.6
Ground	13.2	13.6	13.4			

Tension (5 cm) -Mpa

	1986	1987	$\bar{X}$	1986	1987	$\bar{X}$
Control	.028	.026	.027	.069	.100	.085
Antenna	.060	.022	.058	.090	.062	.072
Ground	.046	.069	.058			

Site Comparison

	Control	Ground
Soil Moisture (5 cm) %	14.7 a[1/]	13.4 a
Tension (5 cm) -Mpa	.027 a	.058 a

	Control	Ground
Soil Moisture (5 cm) %	13.6 a	10.4 b
Tension (5 cm) -Mpa	.056 a	.059 a

Annual Comparison

	Control	vs Ground	Control	vs Antenna
Soil Moisture (5 cm) %	14.6 a	13.6 a	12.4 a	11.6 a
Tension (5 cm) -Mpa	.037 a	.048 a	.062 a	.058 a

[1/]Site or years with the same letter for a specific site

combinations are not significantly different (p=0.05).
may also be a reflection of a large variation in soil moisture within the plots themselves. A significant year by plot within site factor indicates the relationship of soil moisture from one plot to another in the same site does not remain constant from one year to the next. Presently the soil moisture sensors are removed for calibration once a year in the spring. Sensors can not be placed in the same hole after removal due to soil disturbances. Thus after calibration a new location to insert the sensor is randomly chosen within a 4 meter diameter circle around plot center. The differences in year by plot within site factors may reflect changes of and variability in soil moisture within the plots as a result of changes in sensor location and thus, a large variability within plots.

One factor which tends to be uniform for all sites is the relationship of seasonal moisture trends during the two years of the study. Moisture content was higher during June, July, and August of 1987 than during these same months in 1986 (Figures 1.11-1.12). Furthermore during April, May, September, and October 1987 moisture contents were lower than these same months in 1986. Tension measurements for the two years followed similar trends with greater tensions corresponding to lower moisture content and lower tensions with higher moisture content.

Site by Year Interactions: Differences in soil moisture content between the control and the test sites were greater in 1986 than in 1987. There was a difference between the control and the antenna site of 5.3% in 1986 and 1.2% in 1987. ANOVA tests indicated significant differences in the site by year interaction for the control vs antenna analysis (p=0.007). The interaction was not significant at p=0.05 for the control vs ground analysis (p=0.070) but it was significant at p=0.10.

These interaction factors were not significant for the soil tension variables. This again may be related to larger year by plot within site variability.

Detection Limits and Summary: Detection limits associated with soil moisture and tension are much higher than detection limits associated with temperature variables (Table 1.11). The moisture content detection limits computed this year were higher than the limits calculated last year. However, the site by stand type factor had a lower detection limit this year compared to last. Generally the large detection limits are a result of a larger variability in soil moisture among plots in sites and possibly within plots themselves.

Detection limits for soil moisture tension were extremely high (85.0%-150.8%). These high detection limits may be due to various reasons. One contributing factor is that the soil

Figure 1.11

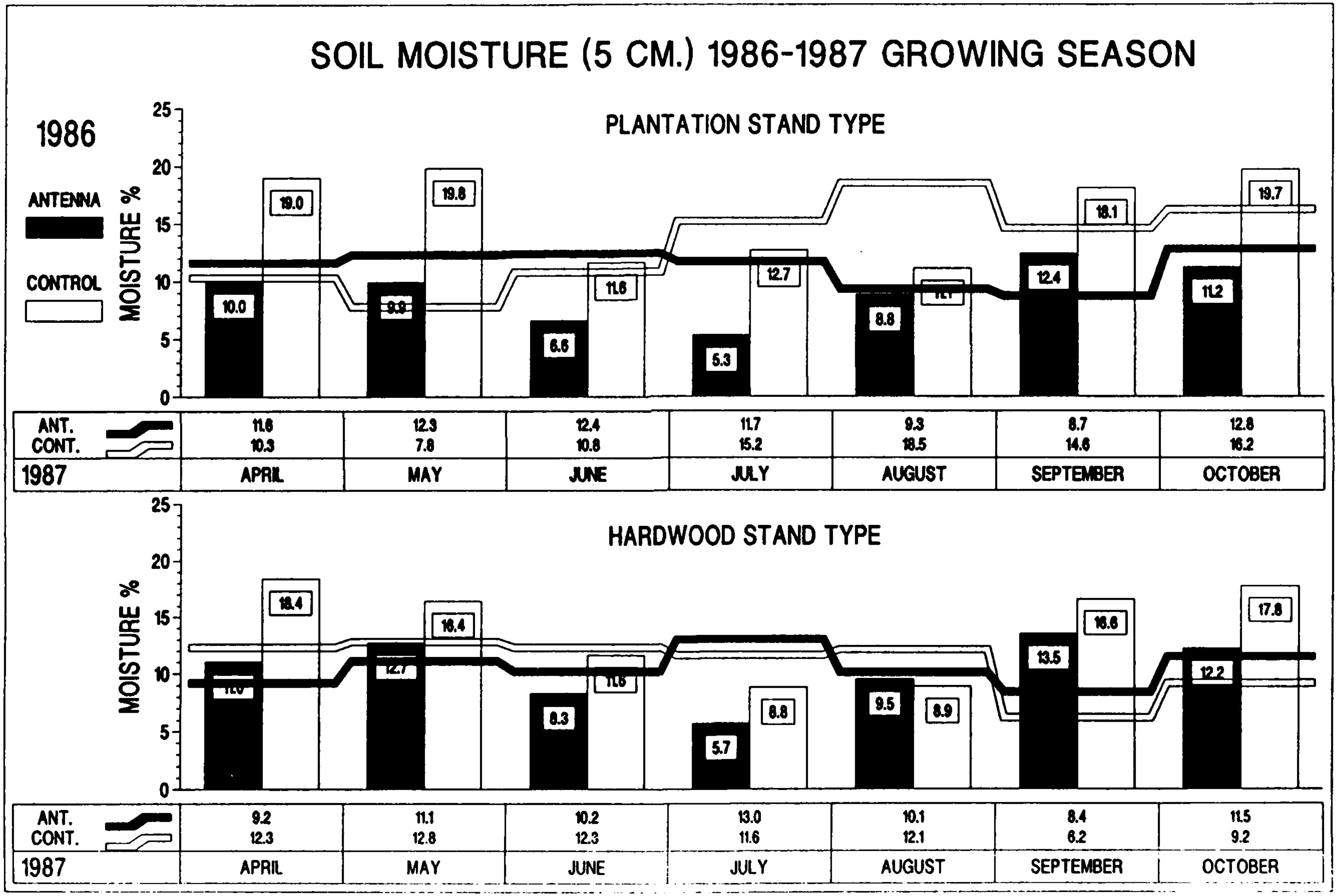
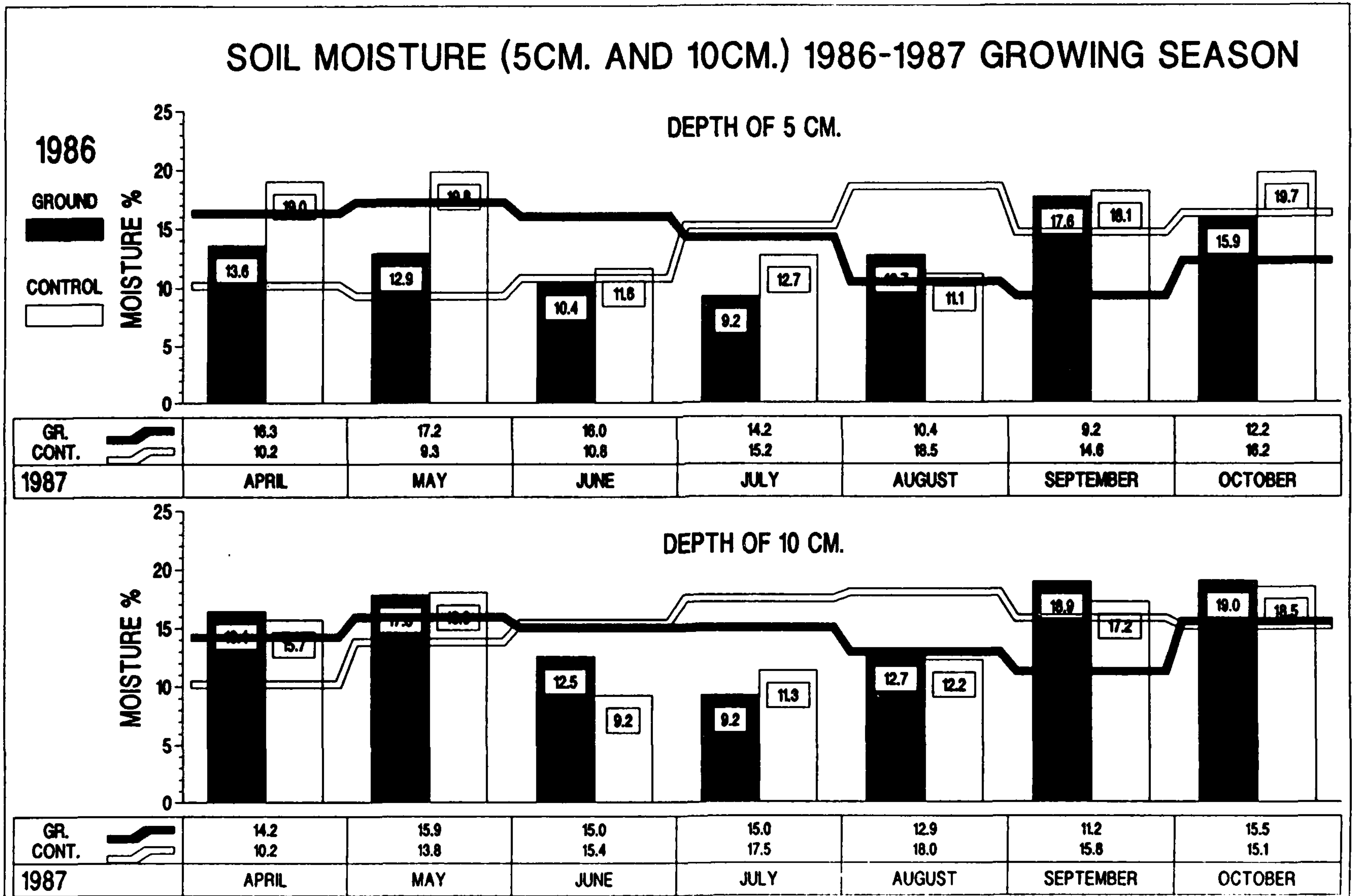

SOIL MOISTURE (5 CM.) 1986-1987 GROWING SEASON
1986
ANTENNA
CONTROL
PLANTATION STAND TYPE
MOISTURE %
25
20
15
10
5
0
10.0
19.0
9.9
19.8
6.6
11.6
5.3
12.7
8.8
12.4
18.1
11.2
19.7
ANT.
CONT.
1987
11.6
10.3
APRIL
12.3
7.8
MAY
12.4
10.8
JUNE
11.7
15.2
JULY
9.3
18.5
AUGUST
8.7
14.6
SEPTEMBER
12.8
16.2
OCTOBER
HARDWOOD STAND TYPE
MOISTURE %
25
20
15
10
5
0
18.4
12.7
16.4
8.3
11.6
5.7
8.8
9.5
8.9
13.5
16.6
12.2
17.8
ANT.
CONT.
1987
9.2
12.3
APRIL
11.1
12.8
MAY
10.2
12.3
JUNE
13.0
11.6
JULY
10.1
12.1
AUGUST
8.4
6.2
SEPTEMBER
11.5
9.2
OCTOBER

Figure 1.12



SOIL MOISTURE (5CM. AND 10CM.) 1986-1987 GROWING SEASON
1986
GROUND
CONTROL
DEPTH OF 5 CM.
MOISTURE %
25
20
15
10
5
0
13.6
12.9
10.4
11.6
9.2
12.7
11.1
17.6
18.1
15.9
19.7
GR.
CONT.
1987
16.3 10.2 APRIL
17.2 9.3 MAY
16.0 10.6 JUNE
14.2 15.2 JULY
10.4 18.5 AUGUST
9.2 14.6 SEPTEMBER
12.2 16.2 OCTOBER
DEPTH OF 10 CM.
MOISTURE %
25
20
15
10
5
0
15.7
12.5
9.2
9.2
11.3
12.7
12.2
18.9
17.2
19.0
18.5
GR.
CONT.
1987
14.2 10.2 APRIL
15.9 13.8 MAY
15.0 15.4 JUNE
15.0 17.5 JULY
12.9 18.0 AUGUST
11.2 15.8 SEPTEMBER
15.5 15.1 OCTOBER

moisture-tension curves (Appendix C) were determined from and applied to each plot, thus adding another source of variation

Table 1.11. Detection limits (p=.05) associated with year and site factors for soil moisture content (5 cm) and soil moisture tension (5 cm).

	Detection Limits		% Mean	
Factor	**Tension -Mpa**	**Content %**	**Tension -Mpa**	**Content %**
Site (Control vs Ground)				
Site	.378	2.55	85.1	18.12
Year	.488	1.47	109.8	10.44
Site x Year	.675	2.04	152.0	14.49
Site (Control vs Antenna)				
Site	.526	1.33	90.5	11.20
Year	.636	0.76	109.4	6.40
Site x Year	.877	1.03	150.8	8.67
Site x Stand Type	.597	1.80	87.2	15.15
Site x Stand Type x Year	.844	2.04	145.2	17.17

to the moisture variables. Also it is questionable if tension has a normal distribution. The tension graph (Appendix C, Figure 1.1) shows that the relationship between tension and moisture content is exponential. Thus the assumptions of normality for this variable may be invalid. In the future these assumptions will be investigated and if distributions of tensions are not normal, the variable will be transformed to normalize the distribution or nonparametric procedures will be used. ANOVA tests using a transformed variable should give more accurate results than tests on a untransformed variable which is not normally distributed.

As stated previously site by year interactions were significant at p=.010 but not at p=0.05 for the control vs test site soil moisture content comparisons. Although soil tension would appear to be a more sensitive measure of the availability of water for plant growth, site by year interactions were not significantly different. Due to the high detection limits associated with tension and to a smaller degree soil moisture content, it can not be determined if these results reflect actual conditions at the sites over time or if the results are an artifact of sampling techniques or analysis procedures. Thus until more rigorous analysis of moisture variables can be performed, it can not be determined if the ELF fields have affected soil moisture at the test sites.

Soil Moisture (depth 10cm)

Site Comparisons: Relationships of soil moisture (10cm) among sites were similar to site relationships using the moisture variables at depths of 5cm. Differences between sites were only significant for the control vs. antenna comparison using soil moisture content as the response variable (Table 1.12). As found with soil moisture (5cm) comparisons, differences in tension among the sites were not significant.

ANOVA tests did indicate significant site by stand type interactions for the control vs antenna ($p=0.030$) using soil moisture content (10cm) as the response variable. Comparisons of the two stand types on these two sites indicated that differences between the sites were greatest in the plantation compared to the hardwood stand type (Figure 1.13). No matter which stand type was considered, the control site had a higher soil moisture content than the antenna site.

With soil tension the relationships among sites and stand types change. Differences between sites is greatest in the hardwood stand rather than in the plantation. Furthermore the soil at the antenna hardwood stand has a greater tension than the soils at the control hardwood stand (Figure 1.14). However ANOVA test did not show any significant site by stand type interactions ($p=0.05$).

Annual Comparisons: Years were not significantly different regardless of the sites compared or the type of soil moisture variable used. As was seen with soil moisture (5cm), variability among and within plots in a site appeared to be high. Thus any actual annual differences in soil moisture may not be detectable.

Site by Year Interactions: ANOVA test for the control vs. ground comparison showed significant site by year interactions for soil moisture content ($p=0.043$). This interaction was not significant for the control vs. antenna comparisons ($p=0.926$) or for any of the soil moisture tension comparisons.

Differences between the significance levels of the two comparisons may be related to variability of soil characteristics of the two stand types. Soil variability in the plantations is greater than at the hardwood sites. This is a residual effect from site disturbances caused by the harvesting of the original stand during plantation establishment. Inclusion of the hardwood stand type in the control vs antenna analysis may stabilize the site by year interactions.

Figure 1.13

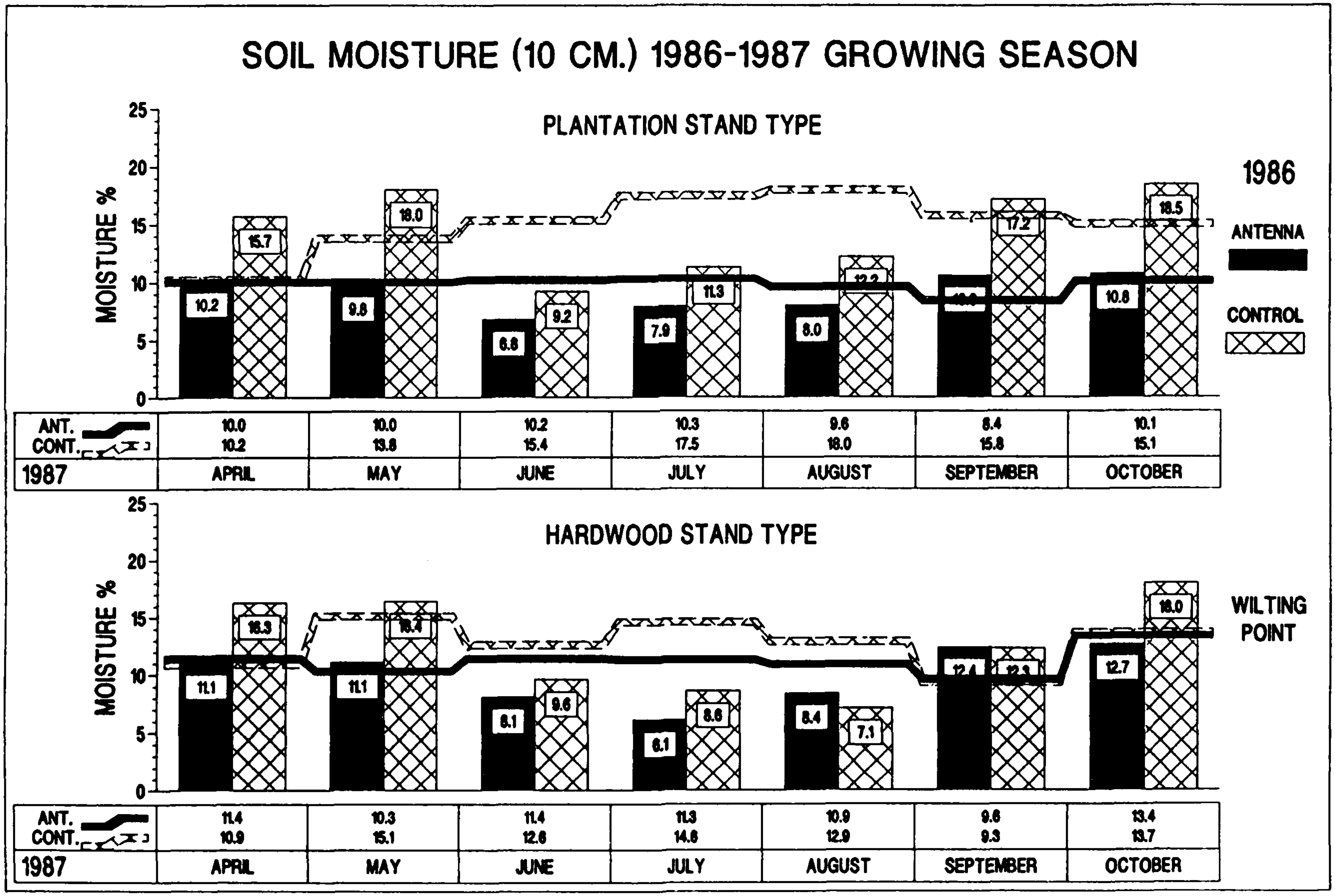

SOIL MOISTURE (10 CM.) 1986-1987 GROWING SEASON
PLANTATION STAND TYPE
MOISTURE %
0
5
10
15
20
25
1986
ANTENNA
CONTROL
10.2
15.7
9.8
18.0
6.8
9.2
7.9
11.3
8.0
17.2
10.8
18.5
ANT.
CONT.
1987
APRIL 10.0 10.2
MAY 10.0 13.8
JUNE 10.2 15.4
JULY 10.3 17.5
AUGUST 9.6 18.0
SEPTEMBER 8.4 15.8
OCTOBER 10.1 15.1
HARDWOOD STAND TYPE
MOISTURE %
0
5
10
15
20
25
WILTING POINT
11.1
16.3
11.1
16.4
8.1
9.6
6.1
8.6
8.4
7.1
12.4
12.3
12.7
18.0
ANT.
CONT.
1987
APRIL 11.4 10.9
MAY 10.3 15.1
JUNE 11.4 12.6
JULY 11.3 14.6
AUGUST 10.9 12.9
SEPTEMBER 9.6 9.3
OCTOBER 13.4 13.7

Figure 1.14

MOISTURE TENSION AT DEPTH OF 10CM.

1986-1987 PLANTATION AND HARDWOOD STANDS

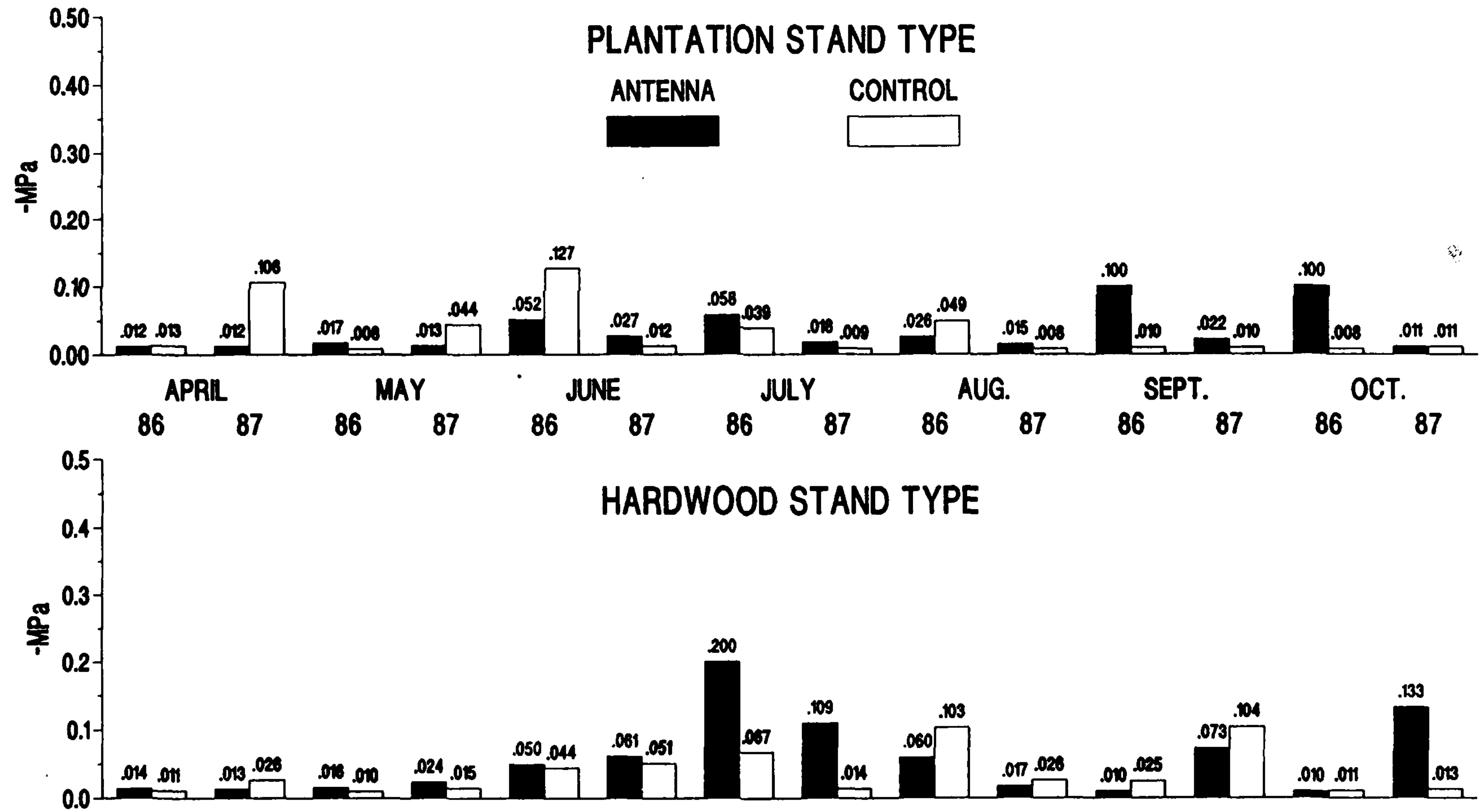


Table 1.12. Comparisons of soil moisture content (10 cm) and soil moisture tension (10 cm) during the 1985-1987 growing season.

Soil Moisture Content (10cm) %

	Plantation Stand Type			Hardwood Stand Type		
	1986	1987	$\bar{X}$	1986	1987	$\bar{X}$
Control	14.6	15.1	14.9	12.6	12.7	12.6
Antenna	9.2	9.8	9.5	10.0	11.2	10.3
Ground	15.2	14.2	14.7			

Tension (10cm) -Mpa

	1986	1987	$\bar{X}$	1986	1987	$\bar{X}$
Control	.042	.023	.033	.044	.038	.041
Antenna	.027	.017	.022	.052	.063	.058
Ground	.058	.020	.039			

Site Comparison

	Control	Ground
Soil Moisture (10 cm) %	14.9 a[1/]	14.7 a
Tension (10 cm) -Mpa	.033 a	.039 a

	Control	Ground
Soil Moisture (10 cm) %	13.7 a	10.1 b
Tension (10 cm) -Mpa	.037 a	.039 a

Annual Comparison

	Control vs Ground		Control vs Antenna	
Soil Moisture (10 cm) %	14.9 a	14.7 a	11.6 a	12.2 a
Tension (10 cm) -Mpa	.050 a	.021 a	.042 a	.035 a

[1/] Site or years with the same letters for a specific site combination are not significantly different (p=0.05).

Detection Limits and Summary: Table (1.13) presents detection limits for soil moisture content (10cm) and soil moisture tension (10cm). Detection limits for these variables and factors are similar to those for soil moisture at the 5cm depth. Again tension detection limits are quit high. Future work on this variable will determine if it is normally distributed and if analysis should be performed on a transformed tension variable.

Table 1.13. Detection limits (p=.05) associated with year and site factors for soil moisture content (10 cm) and soil moisture tension (10 cm).

Factor	Tension	Detection Limit ^{o}C	% Mean	%
Site (Control vs Ground)				
Site	.064	1.90	179.0	12.90
Year	.049	.63	137.1	4.26
Site x Year	.071	.84	198.6	5.68
Site (Control vs Antenna)				
Site	.020	1.77	52.1	14.90
Year	.027	1.07	70.4	9.01
Site x Year	.038	1.49	99.0	12.55
Site x Stand Type	.056	1.23	145.9	10.36
Site x Stand Type x Year	.046	2.45	119.9	20.63

Due to the high detection limits associated with tension and the different site by year interaction probability levels associated with soil moisture content (10cm) and moisture tension (10cm), at this time it can not be determined if ELF fields have had any effect on soil moisture at the depth of 10cm at the test sites.

Precipitation

The amount of precipitation and the distribution of precipitation over time are two primary factors controlling availability of water for plant growth. Thus precipitation is an important factor in the climatic monitoring objectives.

Site Comparisons: Total precipitation was similar among the sites during the three year study period (Figure 1.15). Differences between the control and test sites during 1985 were generally due to the precipitance collectors failure during two storm events at the control site. ANOVA tests

Figure 1.15

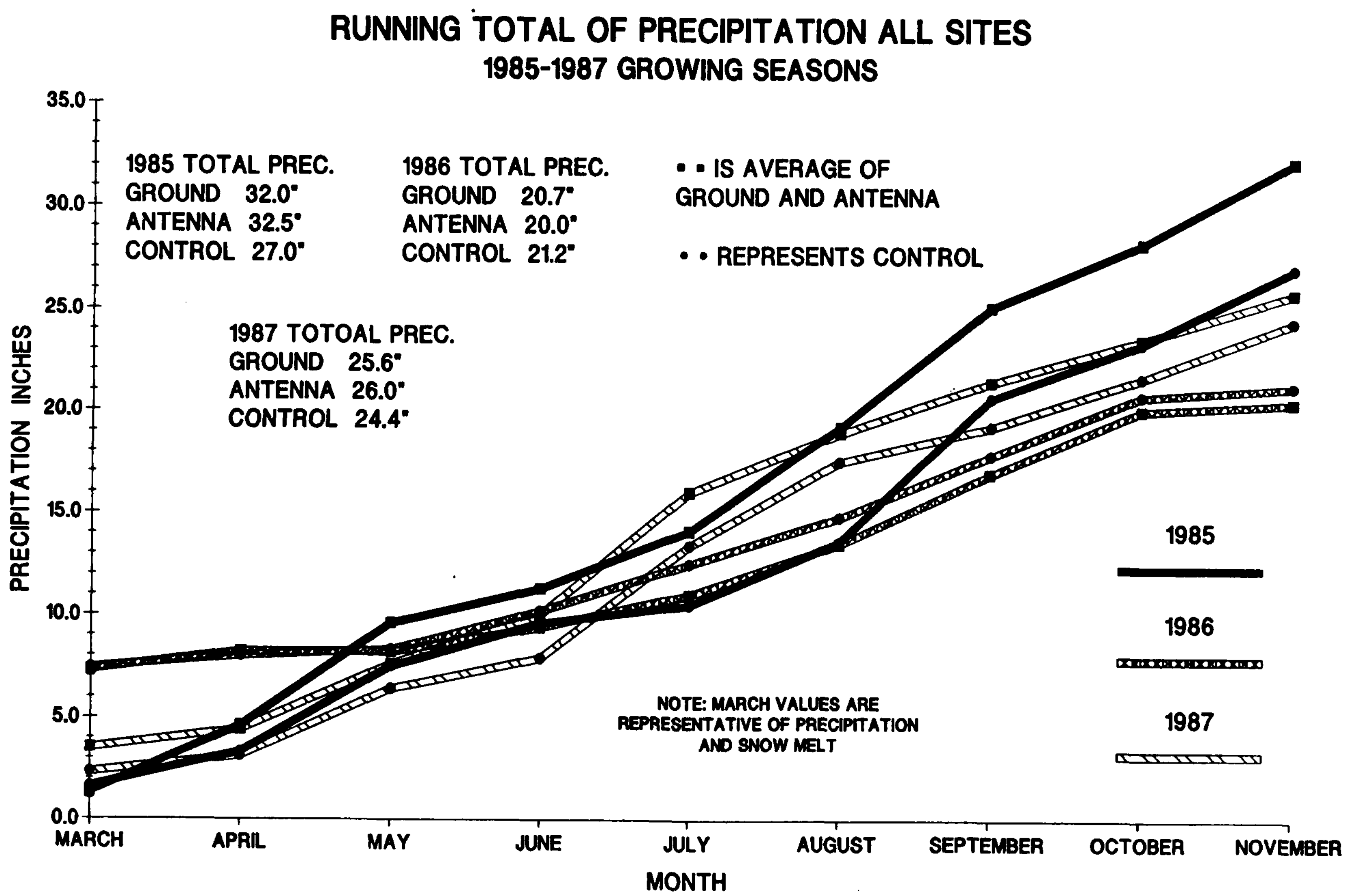


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Table 1.14. Comparison of average total weekly precipitation during the 1985-1987 growing season.

	Inches Precipitation			
	1985	1986	1987	$\bar{X}$
Control	.77	.49	.70	.65
Antenna	.97	.46	.73	.72
Ground	.95	.48	.70	.72

Average Total Weekly Precipitation (Site)

Control	Antenna
.65 a[1/]	.72 a

Control	Ground
.65 a	.72 a

Average Total Weekly Precipitation (Year)

Control & Antenna			Control & Ground		
1985	1986	1987	1985	1986	1987
.87 a	.47 a	.72 a	.86 a	.48 a	.70 a
.87 a	.47 b	.72 ab[2/]	.86 a	.48 b	.70 ab

[1/] Sites or year comparisons with the same letter are not significantly different (p=.05).

[2/] Years with a same letter for a specific site combination are not significantly different (p=.10).

showed no significant differences between sites for the control vs. ground comparisons (p=.629) or the control vs antenna comparison (p=.569).

Annual Comparisons: Average total weekly precipitation in 1986 was approximately .39 inches and .25 inches less than in 1985 and 1987 respectively (Table 1.14). ANOVA tests showed yearly significant differences for the control vs. antenna comparison (p=0.049). Tests with the control vs. ground combination (p=0.057) were not significant at p=0.05 but were at p=0.10. Multiple range tests at the p=0.05 were not able to sort out significant differences among years (Table 1.14). However with a significance level of p=0.10, 1985 was found to have a significantly higher average total weekly precipitation than 1986.

In last years analyses month by year differences were significant. Although there are large differences in precipitation for a given month from one year to the next (Figures 1.16), month by year factors were not significant (p=0.074 for control vs ground comparison, p=0.089 for control vs antenna).

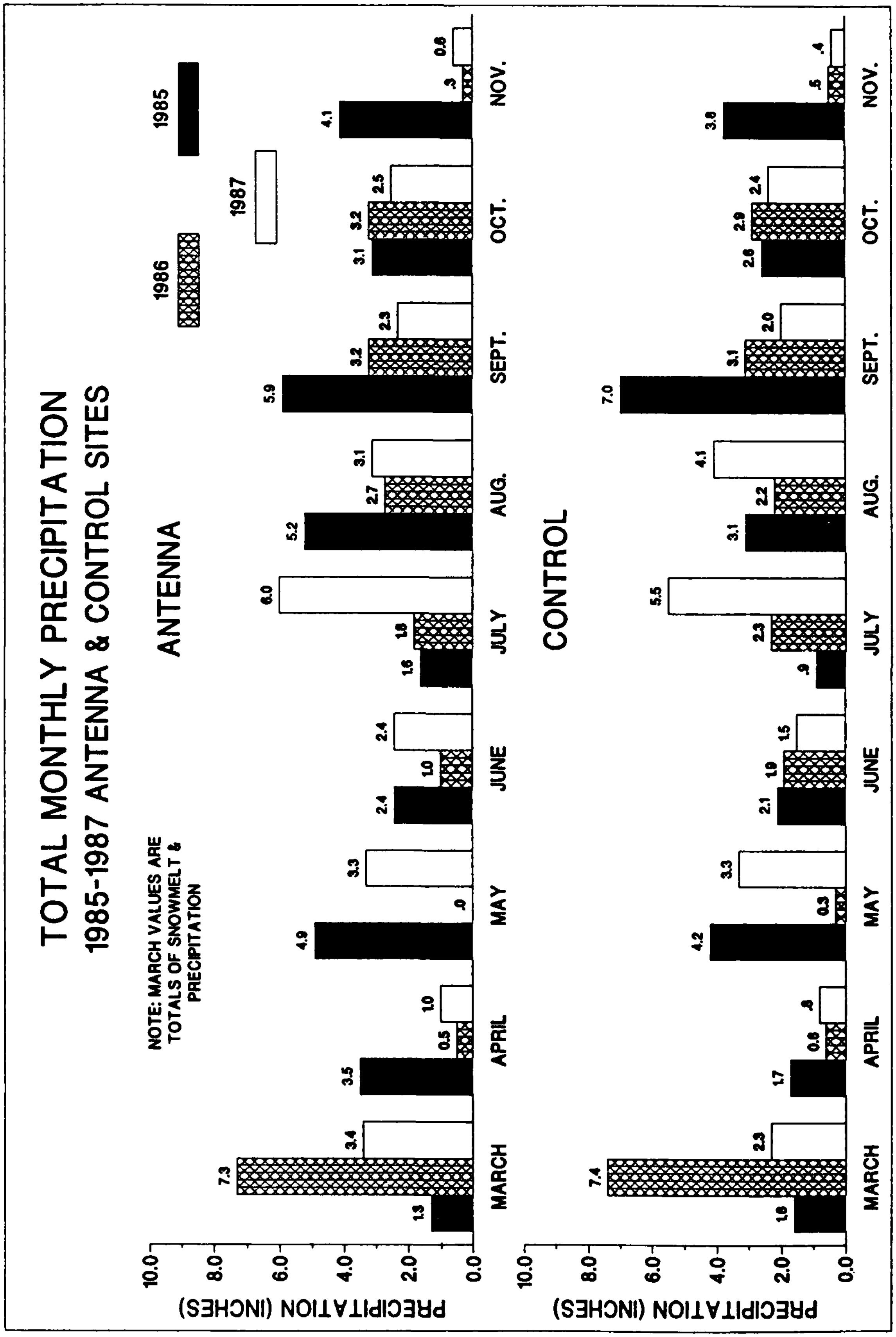
Site by Year Comparisons: No significant differences were found for site by year interactions in either the control vs ground comparison (p=0.769) or the control vs antenna comparison (p=0.739).

Detection Limits: Since only one precipitation collector is located at each site, detection limits for precipitation are relatively high (Table 1.15). Detection limits were

Table 1.15. Detection limits (p=.05) associated with year and site factors for average total weekly precipitation.

Factor	Detection Inches	% Mean
Site (Control vs Ground)		
Site	.273	39.8
Year	.308	44.9
Site x Year	.441	64.3
Site (Control vs Antenna)		
Site	.280	40.6
Year	.319	46.5
Site x Year	.450	65.2

Figure 1.16


TOTAL MONTHLY PRECIPITATION
1985-1987 ANTENNA & CONTROL SITES
1986
1987
1985
NOTE: MARCH VALUES ARE TOTALS OF SNOWMELT & PRECIPITATION
ANTENNA
CONTROL
PRECIPITATION (INCHES)
10.0
8.0
6.0
4.0
2.0
0.0
MARCH
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
1.3
7.3
3.4
3.5
0.5
1.0
4.9
.0
3.3
2.4
1.0
2.4
1.6
1.8
6.0
5.2
2.7
3.1
5.9
3.2
2.3
3.1
3.2
2.5
4.1
.3
0.6
1.6
7.4
2.3
1.7
0.6
.8
4.2
0.3
3.3
2.1
1.9
1.5
.9
2.3
5.5
3.1
2.2
4.1
7.0
3.1
2.0
2.6
2.9
2.4
3.8
.5
.4

between 39.8% and 65.2% of the average weekly total precipitation. The detection limits calculated this year for site and site by year interactions were smaller than last year's calculations. The expression of these limits as a percent of the mean are higher than last year. This was caused by a mistake in the percentage calculations in 1986.

An additional precipitation collector at each site would probably increase the statistical accuracy of our analysis. However rainfall is extremely homogeneous over the area of a given study site. Thus any variation between the collectors would only be due to variation of the equipment and would not give a more accurate measurement on the amounts of rainfall.

Precipitation collectors are located in the plantations and the amounts of rainfall collected are not effected by the vegetation at the plantation. Thus precipitation is considered to be independent of ELF effects and no discussion relative to ELF exposure is included with this section.

Global Solar Radiation

Solar radiation is the primary energy source for photosynthesis as well as the primary factor controlling climatic conditions. Thus solar radiation is continually monitored at the study sites.

Comparisons of global solar radiation did not include observations recorded in July. Data from this month in 1987 was not available due to the lightning strike at the ground site. Thus it was felt that a more suitable comparison of yearly information could be made if July was excluded of the analyses.

Annual Comparisons: Average daily global solar radiation for each month of the growing season is presented in Appendix B (Table 9,11,13). Average daily global solar radiation during the adjusted 1985 growing season (April-June, August-October) was 22.7 and 11.1 Langleys/day higher in 1986 than in 1987 respectively (Table 1.16). However differences between years were not significant (p=0.725).

Analyses last year indicated significant differences in year by month interactions. Last years analysis included the month of July since the solar radiation sensor was operational in July for both 1985 and 1986. Multiple range tests performed last year indicated differences between the 1985 and 1986 July monthly averages. This years analysis which excluded this month found no significant differences in the month by year interaction (p=0.406). Global solar radiation is generally the highest in June and July (Figure 1.17). Thus missing observations from these two months can have a serious effect on the outcome of the statistical analyses.

Figure 1.17

SOLAR RADIATION
(1985-1987 GROWING SEASONS)
GROUND SITE

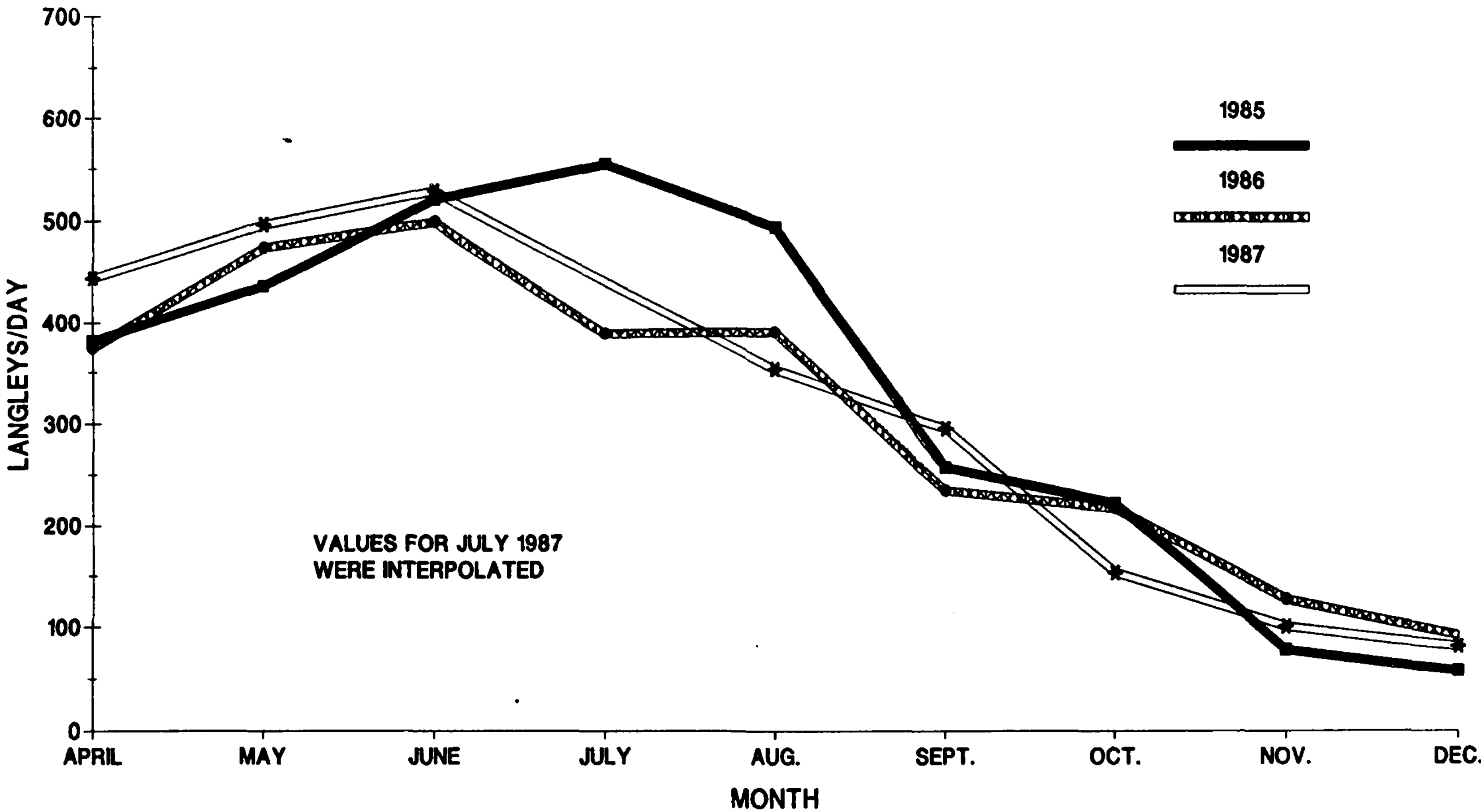


Table 1.16. Average global solar radiation during the 1985-1987 growing seasons and detection limits for year and month by year factors (p=.05)

Global Solar Radiation[1]
(Langleys/Day)

1985	1986	1987
384.4 a[2]	361.7 a	373.3 a

Factor	Detection Limit (Langleys/Day)	% Mean
Year	61.5	16.5
Year x Month	108.5	29.1

[1] Averages and analysis using April-June, August-October July was excluded from the analysis due to missing information from July 1987.

[2] Years with the same letters are not significantly different (p=0.05).

Detection Limits and Summary: The detection limits for the year and the year by month factors were 61.5 and 108.5 Langleys/day respectively (Table 1.16). These values are 20 to 30% lower than the detection limits calculated in last years report.

The global solar radiation sensor is located about 4 meters above the ground in the plantation at the ground site. Thus global solar radiation is independent of ELF fields.

Relative Humidity

Atmospheric humidity is an influential factor determining rates of plant transpiration and respiration. Humidity is related to vapor pressure gradients which affects the amount of evapotranspiration and evaporation from a given land area. In an attempt to fully monitor the climate at the study sites, relative humidity is measured by the ambient monitoring systems.

As a result of sensor repairs this is the first year that relative humidity has been monitored during the entire growing season. Thus annual comparisons are limited to only the months of July through October during 1985 and 1987. Site and month comparisons are only made with the 1987 data.

Site Comparisons: In 1987 relative humidity was higher at the test sites than at the control site (Table 1.17). Differences were significant ($p=0.001$) for the control vs antenna and control vs ground ($p=0.003$). Differences among months during the growing season were significant ($p<0.001$) for both comparison but month by site interactions were not significant ($p=.570$).

Seasonally relative humidity increased from April through July and then stabilized after July (Figure 1.18). Although no statistical tests could be made to compare seasonal trends among sites during the entire study period, these trends appear to be stable among the sites and years (Figure 1.18).

Annual Comparisons: Differences between 1985 and 1986 were significant for the control vs antenna comparisons ($p=0.026$) but not for the control vs ground comparison ($p=0.179$). Using the control vs antenna comparison, relative humidity was 4.8% higher in 1987 compared to 1985 (Table 1.17). Year by site interactions were significant for both the control vs antenna comparison ($p=0.003$) and the control vs ground comparison ($p=0.014$). The data indicate that the differences in the control and tests sites were smaller in 1985 compared to 1987.

Detection Limits and Summary: Site and year factors had low detection limits for each of the site comparisons. These limits were among the lowest calculated among the climatic variables measured.

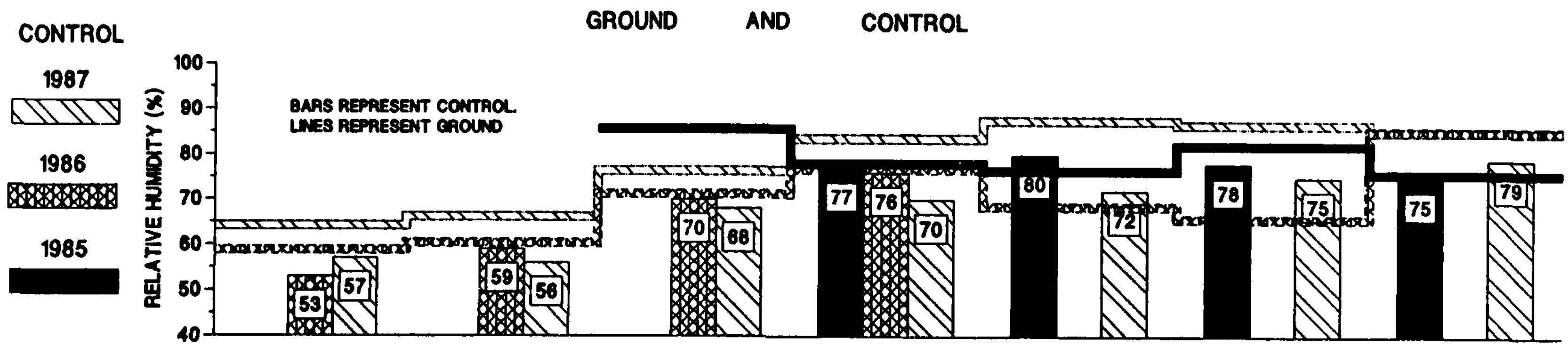
Relative humidity sensors are located 2 meters above the ground at the plantations. At this time the vegetation in the plantations does not effect relative humidity and thus no summary of ELF effects on this variable are included in the report.

Photosynthetically Active Radiation (PAR)

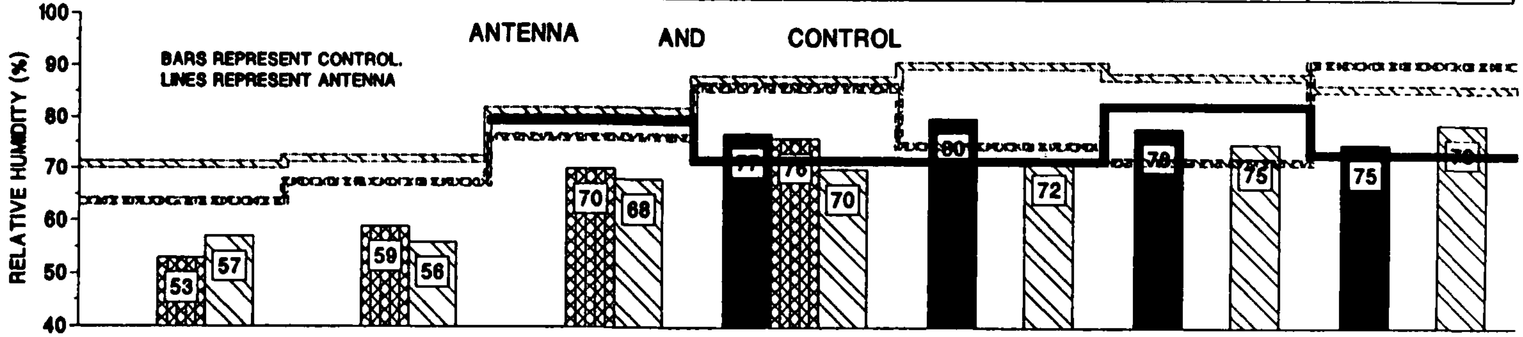
Photosynthetically active radiation is measured in the hardwood stand at the control an antenna sites. This climatic variable should be sensitive to possible ELF related changes in the canopy of the hardwood stand. Reduction of foliage biomass or changes in the timing of leaf expansion or leaf fall would alter the amount of radiation reaching the forest floor over the duration of the growing season. This type of change would effect forest floor vegetation growth and microclimate in the hardwood stands.

Figure 1.18

RELATIVE HUMIDITY
(1985-1987 GROWING SEASON)



	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
GROUND 1985			85.6	78.0	76.5	82.1	75.8
GROUND 1986	58.8	60.4	71.2	76.8	68.5	65.7	85.3
GROUND 1987	64.1	66.1	76.4	83.6	87.6	86.7	85.2



	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
ANTENNA 1985			79.5	71.7	71.6	82.4	73.1
ANTENNA 1986	63.6	67.3	76.2	85.8	74.6	71.6	90.6
ANTENNA 1987	70.7	71.9	81.3	87.5	90.2	88.1	85.9

Table 1.17 Comparison of relative humidity during the 1986 and 1987 growing seasons and detection limits associated with site and year factors (p=0.05).

	Relative Humidity (1987) %	
	Control	**Antenna**
	67.7 a[1/]	82.2 b
	Control	**Ground**
	67.7 a	78.7 b

	Relative Humidity %	
	1985	**1987**
Control vs Antenna	76.2 a	81.0 b
Control vs Ground	77.8 a	79.9 a

	Detection Limits %	% Mean
Control vs Antenna		
Site [2/]	1.38	2.02
Month	3.10	3.76
Month by Site	4.38	5.32
Year [3/]	3.77	4.78
Year by Site	5.16	6.56
Control vs Ground		
Site	1.94	2.65
Month	2.79	3.82
Month by Site	3.95	5.40
Year	3.48	4.42
Year by Site	4.92	6.24

[1/] Year or site comparisons with the same letter for a specific site combination are not significantly different (p=0.05)

[2/] Calculated from 1987 relative humidity.

[3/] Calculated from July-October 1985 & 1986

Site and Annual Comparisons: Comparisons of sites and years are limited to the months of April through June, due to the downtime of the platforms. Since PAR sensors were not operational until June of 1985, 1986 through 1987 are the only years used in PAR comparisons. Figure (1.19) shows that PAR is dramatically reduced during May and June when leaf expansion of the hardwood stands occur.

Averages of PAR were 2.13 Einsteins/day higher at the antenna site than at the control site. Average PAR was also .88 Einsteins/day higher in 1986 than in 1987 (Table 1.18). Neither of these two factors , site or year, were significant (p=.275 and p=.123). Site by year factors were also not significantly different (p=.0852).

Table 1.18. Comparison of photosynthetically active radiation during the 1986 and 1987 growing seasons and detection limits associated with site and year factors (p=0.05).

Average Daily PAR[1]
(Einsteins/Day)

	1986	**1987**	**$\bar{X}$**
Control	7.65	6.83	7.24 a
Antenna	9.84	8.90	9.37 a
$\bar{X}$	8.75 a[2]	7.87 a	

Factor	**Detection Limits PAR**	**% Mean**
Site	4.29	51.6
Year	1.28	15.4
Site x Year	1.93	23.2
Month x Site	5.46	65.7
Month x Year	5.26	63.3

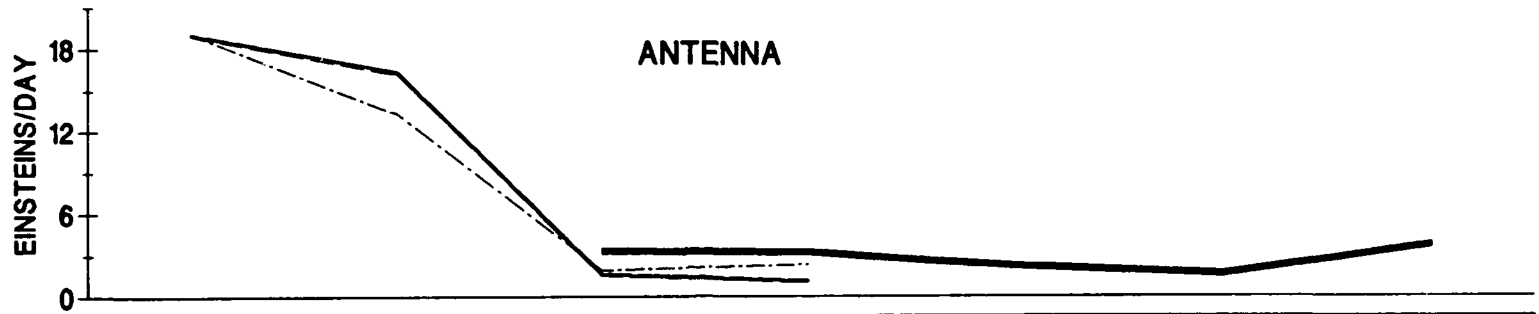
[1] Values determined for only April-July.

[2] Site or year comparison with the same letter are not significantly different at (p=.05).

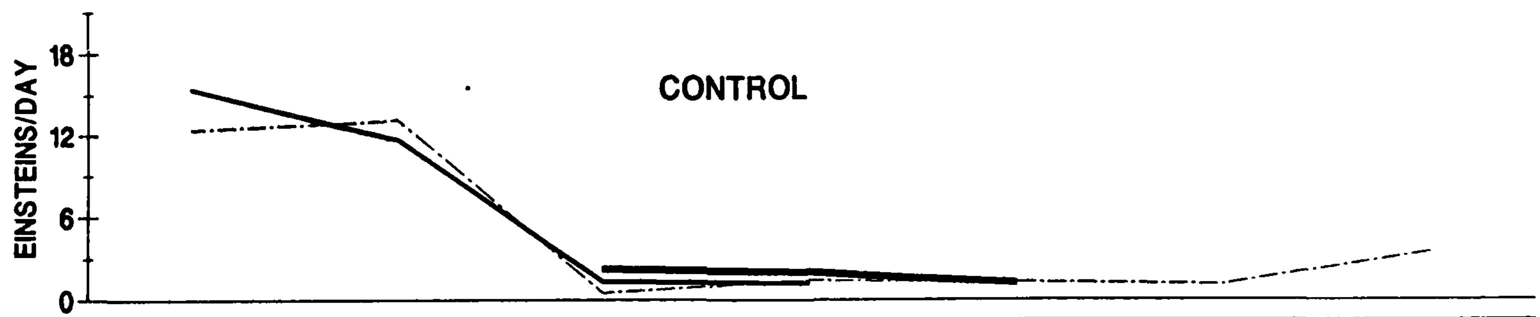
Detection Limits and Summary: Table (1.18) presents the detection limits for PAR. These values are similar to the limits calculated in 1986. Detection limits for PAR had similar values to other variables which are measured with only one sensor per plot.

Figure 1.19

PHOTOSYNTHETICALLY ACTIVE RADIATION
(1985-1987 GROWING SEASONS)
(30 cm above ground in hardwood stand types)



MONTH	APRIL	MAY	JUNE	JULY	AUG.	SEPT	OCT.
1985			3.3	3.2	2.2	1.6	3.7
1986	19.0	16.3	1.6	1.1			
1987	19.1	13.3	1.9	2.3			



MONTH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
1985			2.2	2.0	1.2		
1986	15.4	11.7	1.3	1.2			
1987	12.4	13.2	.5	1.4	1.3	1.1	3.5

Since no significant differences were found for the site, year, or site by year interactions, there was no evidence to indicate that the present levels of ELF exposure has effected PAR at the antenna hardwood site.

Air Temperature (30cm above ground)

These sensors were not operational this year. Thus no further comparisons of this variable were made

Summary

This report summarizes the first year of antenna operation at the test sites. Our analyses indicate that temperature variables, which have the lowest detection limits and highest measurement accuracy, do not appear to have been affected by the present level of ELF field exposure. Although it is felt that air or soil temperature in the hardwood stand would be more sensitive to ecological changes possibly caused by ELF, relationships for these variables between the hardwood and plantation stand types were stable over the duration of the study. There was also no evidence to indicate that ELF affected the amount of photosynthetically active radiation received within the hardwood stands.

Soil moisture content, which had higher detection limits than either air or soil temperature, did show changes in relationships between the control and tests sites in 1987. However as a result of the higher level of variation associated with soil moisture and the differences between results related to soil moisture content and soil moisture tension, it is not warranted at this time to conclude that soil moisture was effected by the antenna operation.

Nutrient Monitoring

Precipitation Chemistry

As part of the ambient monitoring program the nutrient contents of rainwater samples were determined to estimate nutrient inputs from precipitation at all three sites during the growing seasons. A collection bucket having a fitted funnel attachment was placed on one plantation plot at each study site. The buckets were checked once a week and if rainfall had occurred a water sample was removed for nutrient analysis. Phenolmercuric acetate was added to each bucket to prevent nutrient changes due to microbial activity prior to collection. The water samples were frozen and stored at -7.8°C until chemical analysis. Cation concentrations were determined on a Perkin-Elmer Model 5000 atomic absorption

spectrometer. Anions were analyzed on a Dionex Model 10 ion chromatograph.

Progress

Average nutrient concentrations of rainwater were higher in 1986 than in 1985 but only Mg levels were significantly different (Table 1.19). However, there were no significant concentration differences for any of the nutrients among the three study locations for either year. Total nutrient additions/site which were calculated from weekly nutrient concentration values and rainfall amounts, also showed no significant differences among the sites (Table 1.20). The higher nutrient additions in 1986 are a reflection of the greater precipitation amounts which occurred in 1985 as compared to 1986 (63.9 vs 33.2 cm).

Table 1.19 Average nutrient concentrations (ppm) of rainwater at the three ELF study sites: April-October*

Site	Ca	Mg	K	NO_3	SO_4
1985					
Ground	1.48	0.27	0.65	1.42	3.31
Antenna	1.92	0.30	0.59	1.45	3.66
Control	1.82	0.37	0.89	1.64	3.74
Average	1.74 A/	.31 A/	.71 A/	1.50 A/	3.57 A/
1986					
Ground	2.25	0.83	1.25	1.77	3.67
Antenna	2.06	0.48	1.10	1.48	3.04
Control	2.17	0.65	0.96	1.79	3.77
Average	2.16 A/	.65 B/	1.10 A/	1.68 A/	3.49 A

*PO_4 concentrations were analyzed but were less than 0.1 ppm for all samples.

Values for a given nutrient with same letter not significantly different at p=.05.

Table 1.20. Average nutrient contents (kg/ha) of rainwater at the three ELF study sites: April-October.

Site	Ca	Mg	K	NO_3	SO_4
1985					
Ground	10.4	2.0	7.2	9.8	26.4
Antenna	12.2	2.3	7.3	9.8	29.9
Control	10.4	2.3	6.1	9.2	21.6
Average	11.0^{A}	2.2^{A}	6.9^{A}	9.6^{A}	26.0^{A}
1986					
Ground	6.3	1.9	3.2	5.6	11.6
Antenna	5.4	1.3	2/6	4.7	9.6
Control	7.2	2.0	2.6	5.8	11.2
Average	$2.16^{B/}$	$1.7^{B/}$	2.8^{B}	$5.4^{B/}$	10.8^{B}

Values for a given nutrient with same letter not significantly different at p=.05.

While growing season nutrient additions to the sites have been relatively stable, more pronounced differences occurred in the timing of additions with distinct monthly differences (Figures 1.20-1.24). Most monthly nutrient deposition appears to vary with precipitation amounts with higher levels of precipitation being associated with higher deposition levels (Figure 1.25). Thus differences in precipitation for a particular month from year to year resulted in significant differences in depostion of S, Ca, Mg, and K (Table 1.21). However, when site is considered in the analysis, we find that the relationships among sites are stable with no differences among sites within a given year.

Table 1.21. Results of analyses examining year, month, and site interactions of atmospheric deposition data.

	NO_3	SO_4	Ca	Mg	K
	-----------	----P	Value	------	------
Year x Month	.163	.013	.017	.005	.000
Year x Month x Site	.793	.872	.580	.503	.558

Figure 1.20

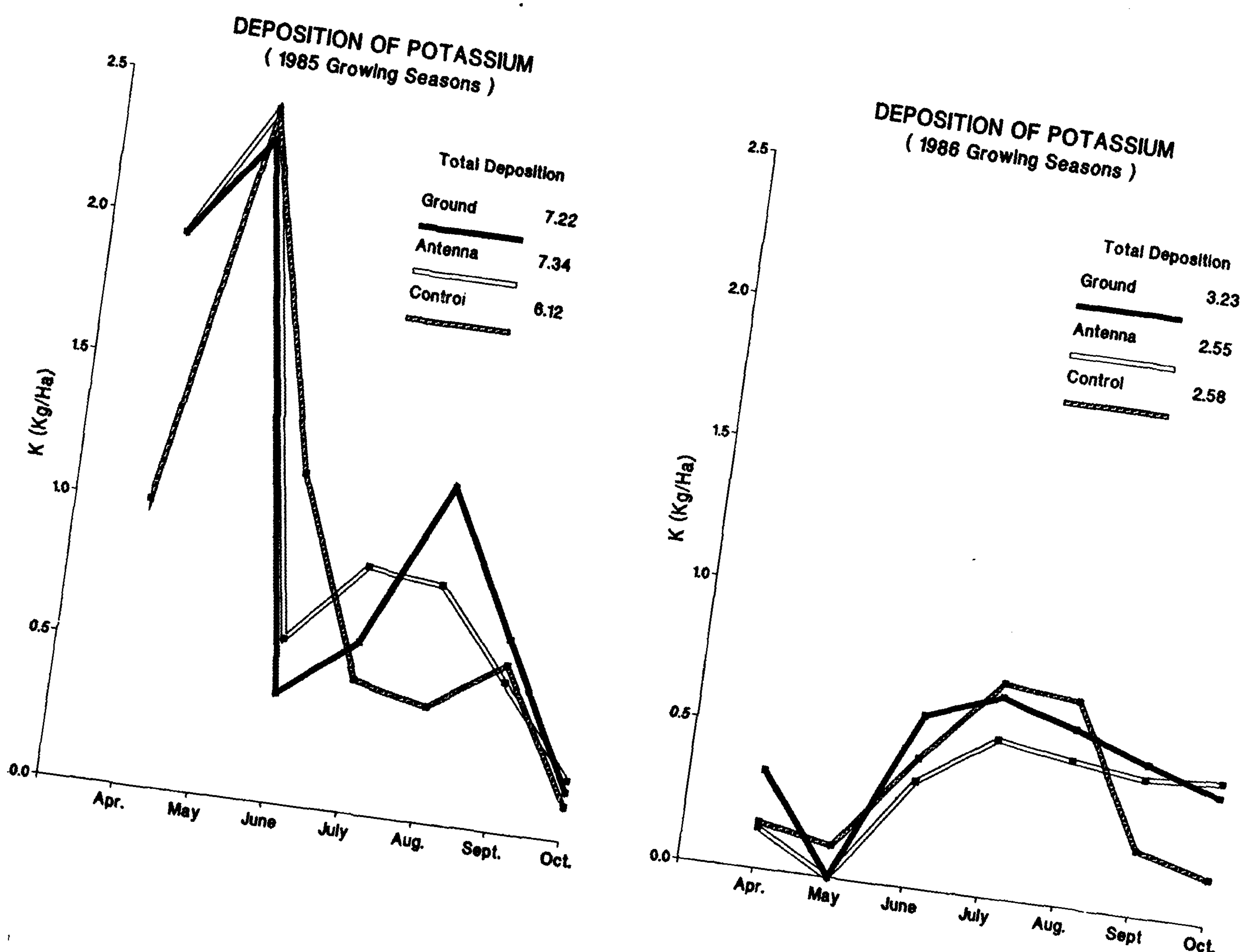
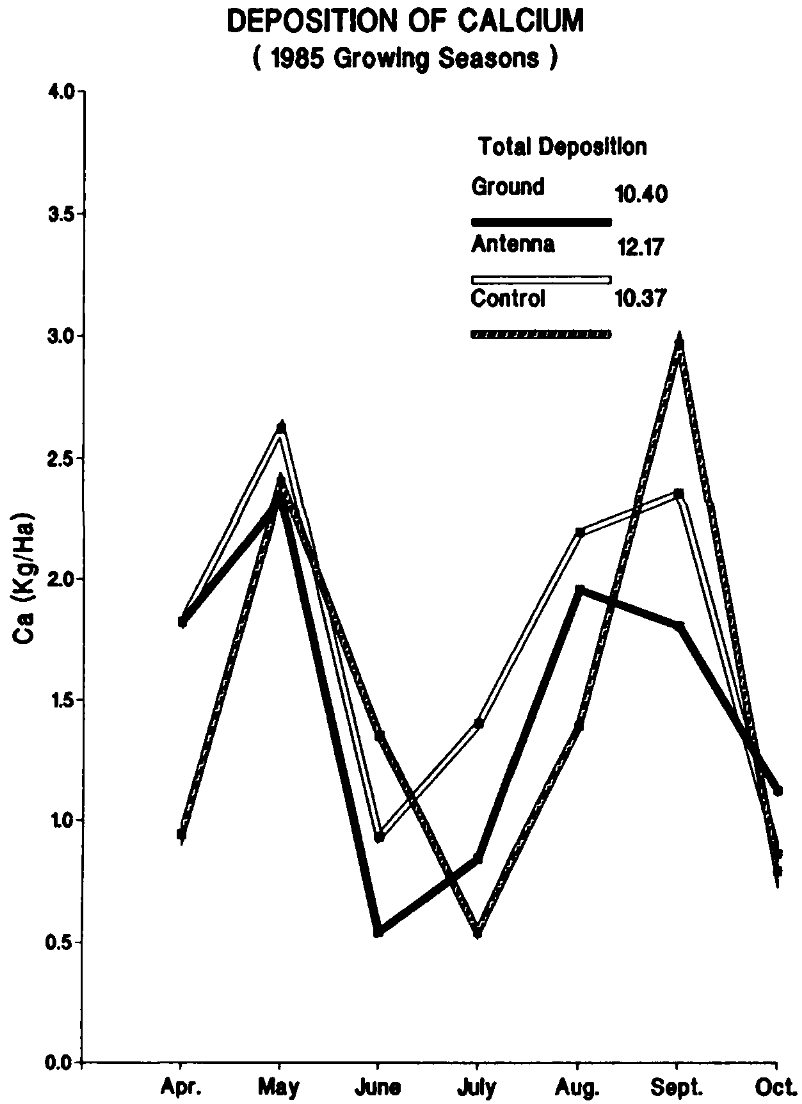
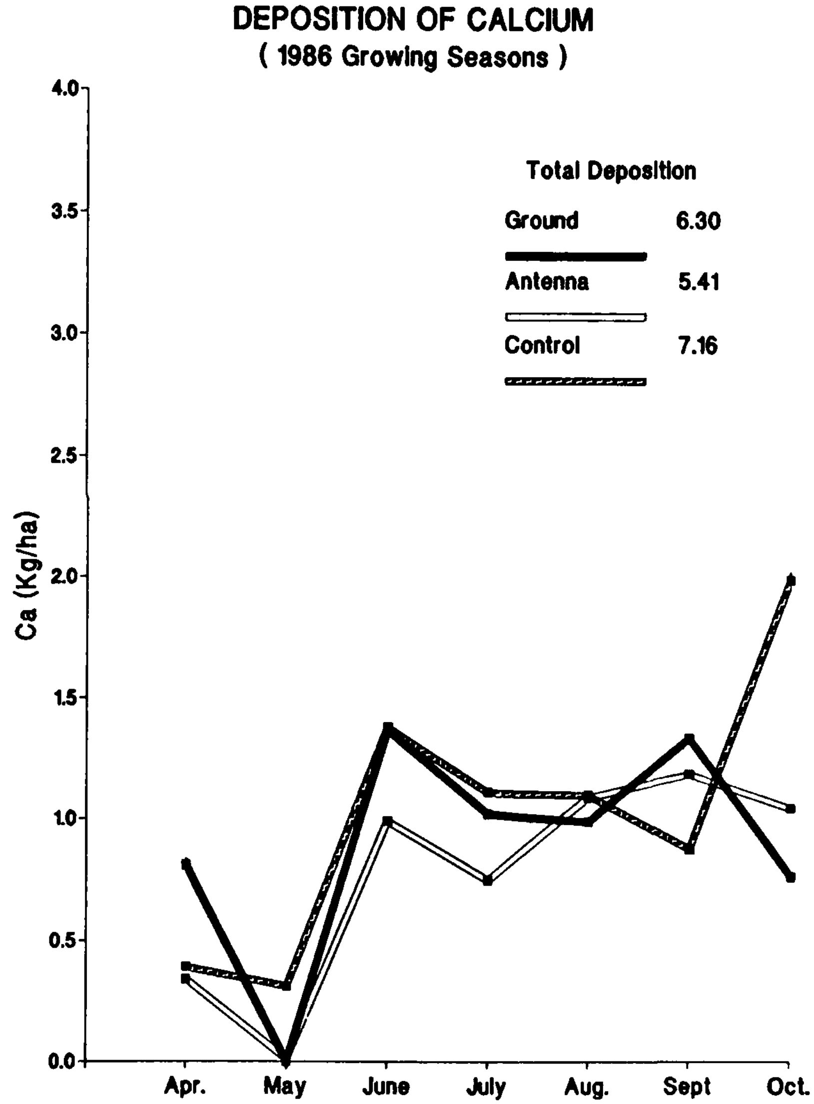

DEPOSITION OF POTASSIUM
(1985 Growing Seasons)
K (Kg/Ha)
2.5
2.0
1.5
1.0
0.5
0.0
Apr.
May
June
July
Aug.
Sept.
Oct.
Total Deposition
Ground 7.22
Antenna 7.34
Controi 6.12
DEPOSITION OF POTASSIUM
(1986 Growing Seasons)
K (Kg/Ha)
2.5
2.0
1.5
1.0
0.5
0.0
Apr.
May
June
July
Aug.
Sept
Oct.
Total Deposition
Ground 3.23
Antenna 2.55
Control 2.58

Figure 1.21

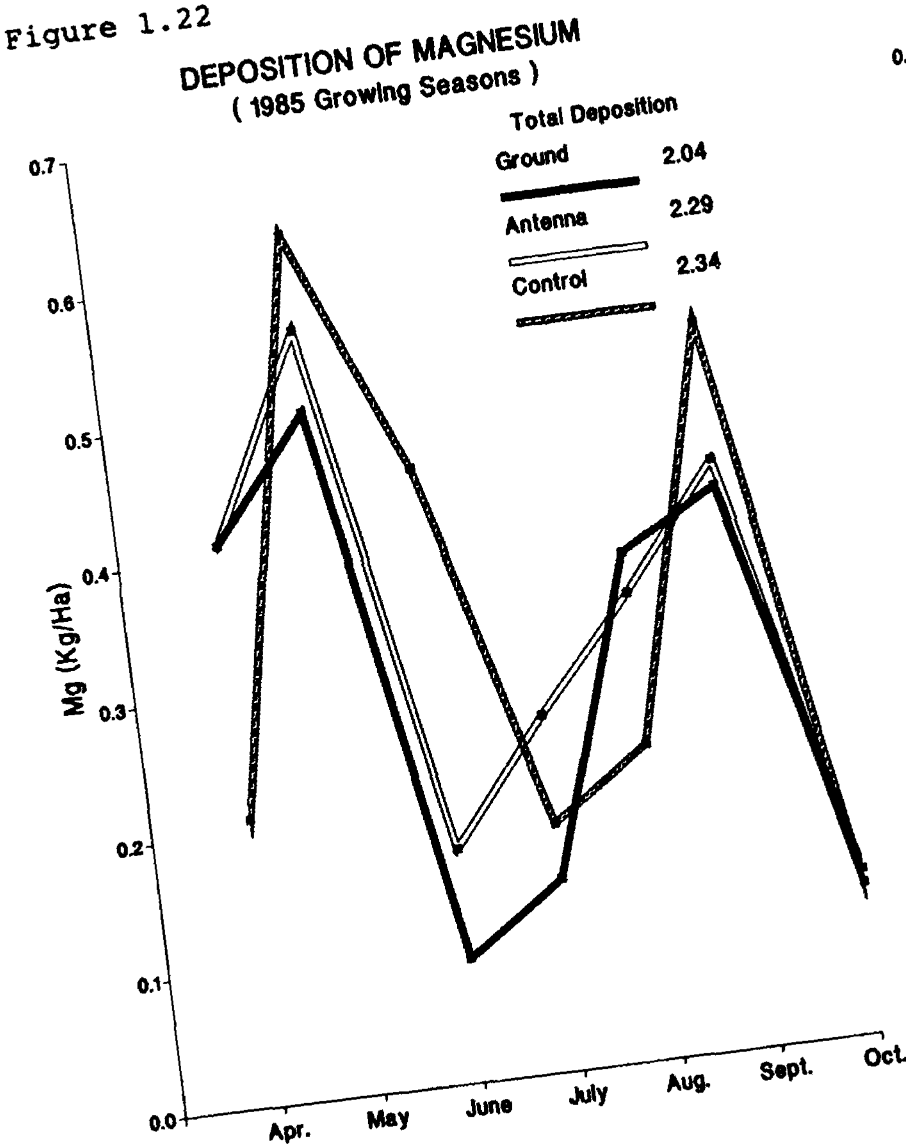


DEPOSITION OF CALCIUM
(1985 Growing Seasons)
Total Deposition
Ground 10.40
Antenna 12.17
Control 10.37
Ca (Kg/Ha)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Apr.
May
June
July
Aug.
Sept.
Oct.



DEPOSITION OF CALCIUM
(1986 Growing Seasons)
Total Deposition
Ground 6.30
Antenna 5.41
Control 7.16
Ca (Kg/ha)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Apr.
May
June
July
Aug.
Sept
Oct.

Figure 1.22


DEPOSITION OF MAGNESIUM
(1985 Growing Seasons)
Total Deposition
Ground 2.04
Antenna 2.29
Control 2.34
Mg (Kg/Ha)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Apr.
May
June
July
Aug.
Sept.
Oct.

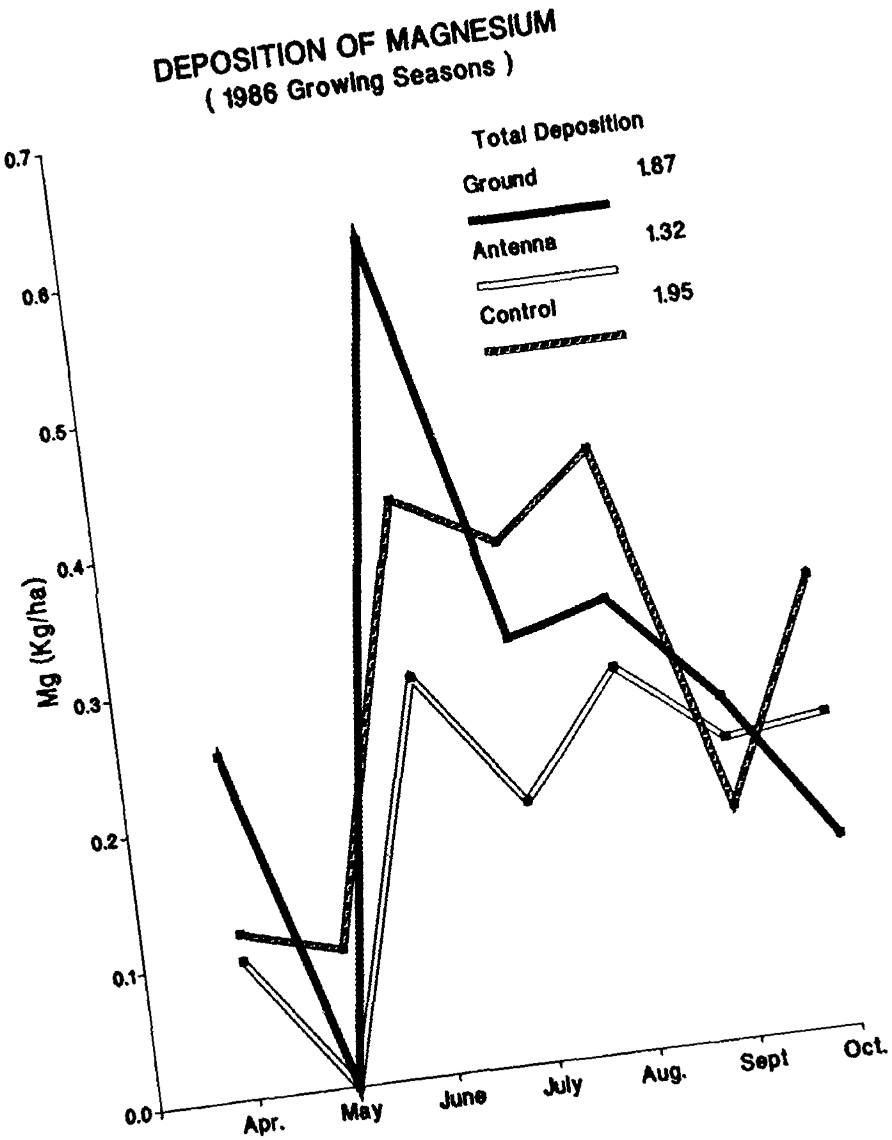
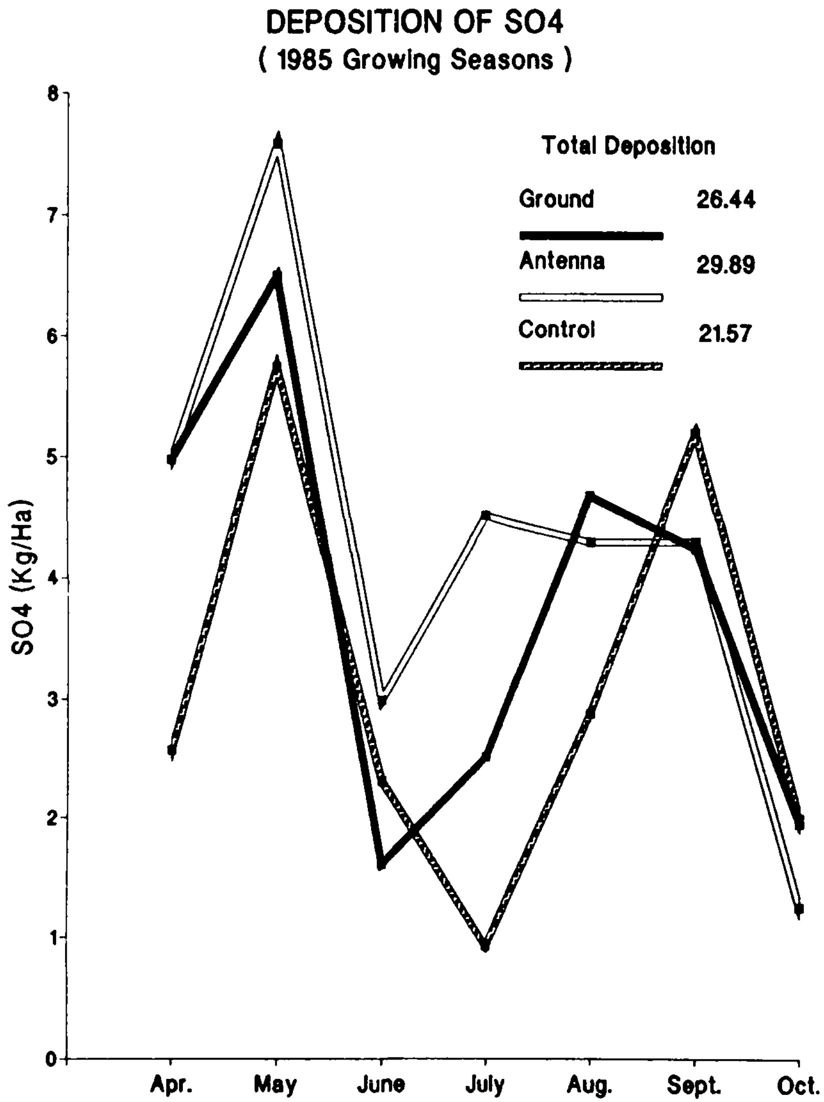

DEPOSITION OF MAGNESIUM
(1986 Growing Seasons)
Total Deposition
Ground 1.87
Antenna 1.32
Control 1.95
Mg (Kg/ha)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Apr.
May
June
July
Aug.
Sept
Oct.

Figure 1.23


DEPOSITION OF SO4
(1985 Growing Seasons)
SO4 (Kg/Ha)
0
1
2
3
4
5
6
7
8
Apr.
May
June
July
Aug.
Sept.
Oct.
Total Deposition
Ground 26.44
Antenna 29.89
Control 21.57

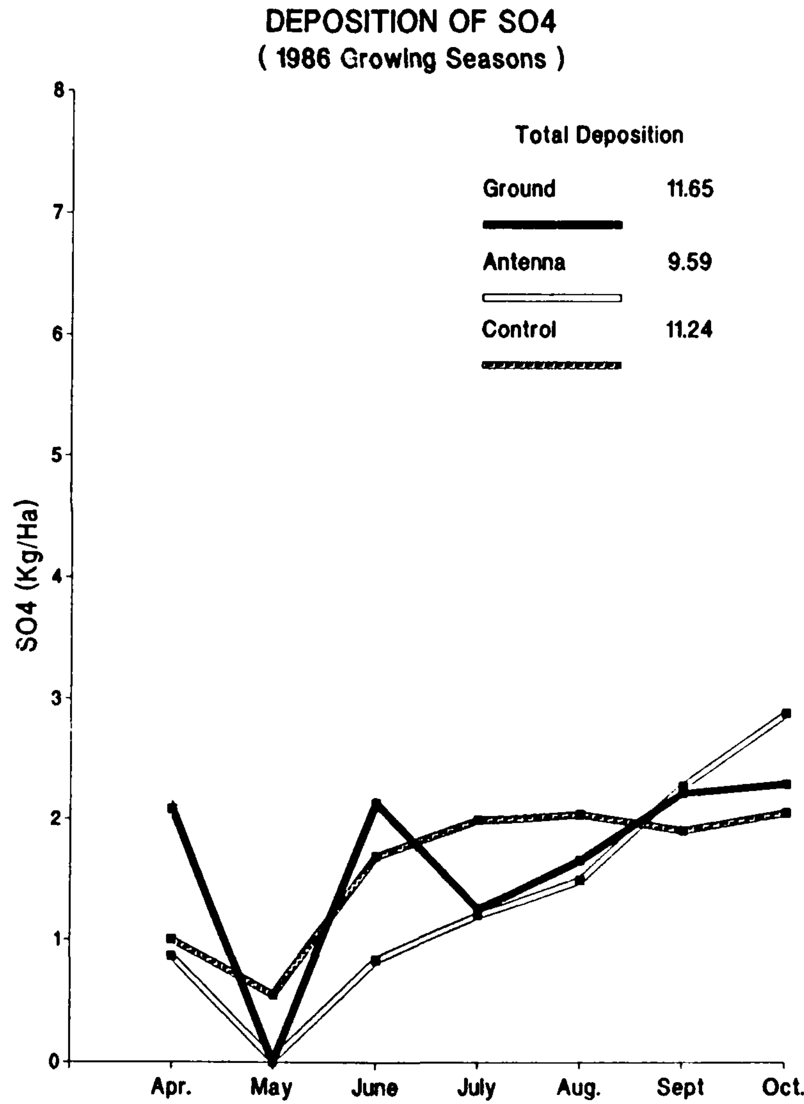

DEPOSITION OF SO4
(1986 Growing Seasons)
SO4 (Kg/Ha)
0
1
2
3
4
5
6
7
8
Apr.
May
June
July
Aug.
Sept
Oct.
Total Deposition
Ground 11.65
Antenna 9.59
Control 11.24

Figure 1.24

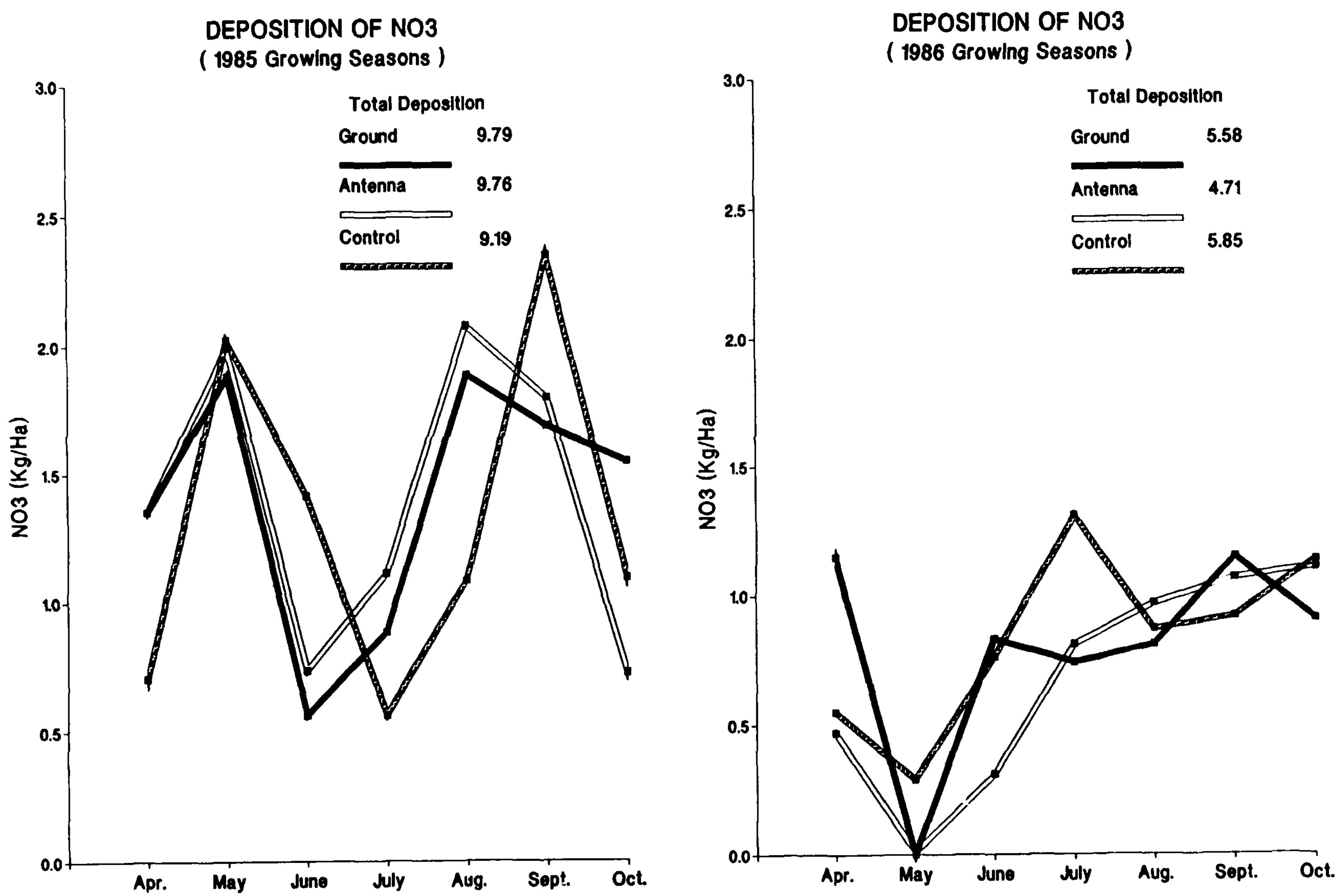
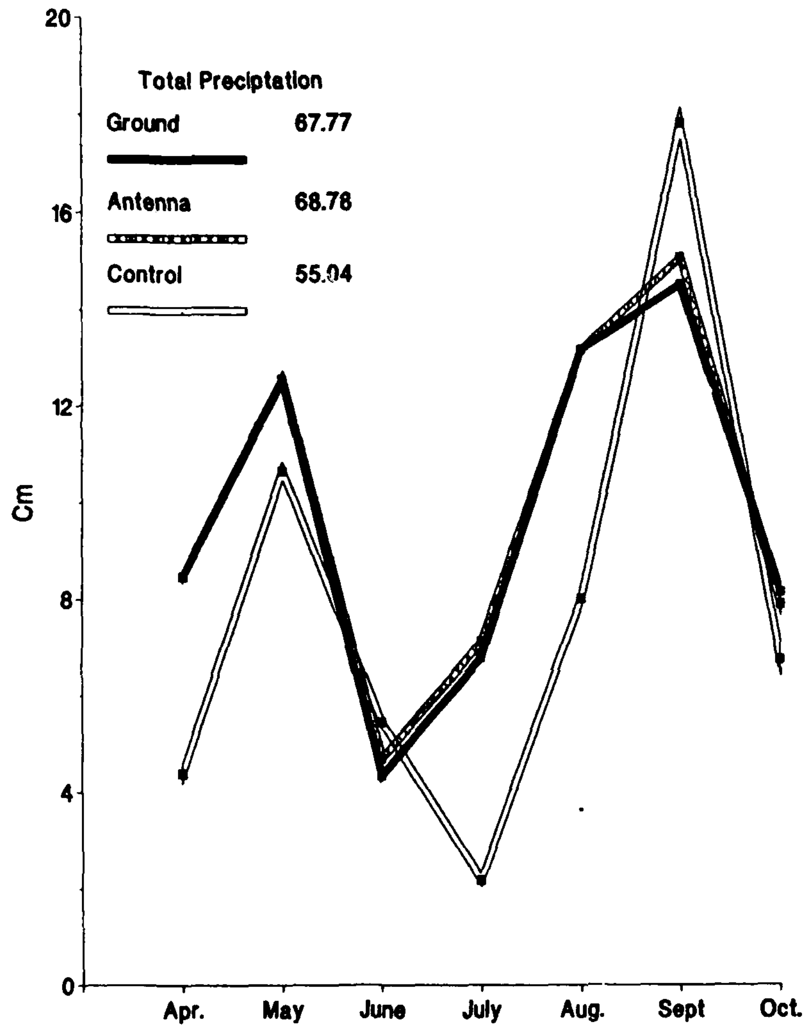
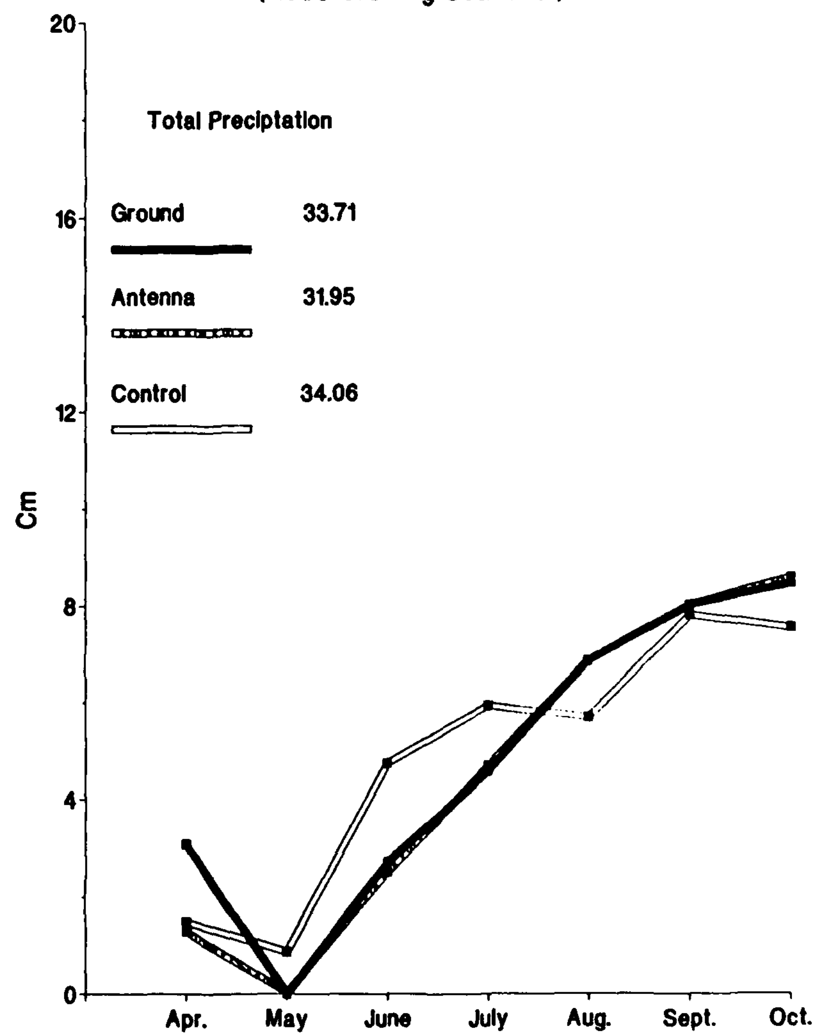

DEPOSITION OF NO3
(1985 Growing Seasons)
Total Deposition
Ground 9.79
Antenna 9.76
Control 9.19
NO3 (Kg/Ha)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Apr.
May
June
July
Aug.
Sept.
Oct.
DEPOSITION OF NO3
(1986 Growing Seasons)
Total Deposition
Ground 5.58
Antenna 4.71
Control 5.85
NO3 (Kg/Ha)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Apr.
May
June
July
Aug.
Sept.
Oct.

Figure 1.25

PRECIPITATION
(1985 Growing Seasons)



PRECIPITATION
(1986 Growing Seasons)



Deposition may play a significant role as a fertilization treatment on the sites. For example, using the nutrient content of overstory biomass data reported by Crow (1984) for a stand similar to those on the ELF sites we can approximate annual stand nutrient demands of 4 kg/ha N, 4kg/ha K, 9kg/ha Ca and .6 kg/ha Mg. Although a crude comparison, each of these amounts is similar to the amount of deposition for the growing season suggesting that deposition is an important source of nutrients on an annual basis (Figures 1.20-1.24).

Timing of deposition might also play an important role in the seasonal growth pattern of trees on the sites. Hardwood growth modeling efforts in this study have shown soil K levels to explain variability in growth observed on the sites (Element 2). In the next year we will be evaluating whether atmospheric deposition might also be used successfully in growth modeling efforts and covariate analyses.

Soil Nutrients

Tree productivity analysis done during the past year indicated that soil nutrients are valuable covariates in explaining site and year differences (see Element 2). In addition, future efforts in analyzing northern red oak foliar nutrients and litter production will include soil nutrient information. Thus the objective of the soil nutrient study is to evaluate soil nutrients as a covariate in the tree productivity, litter production, and northern red oak nutrition studies.

Sampling and Data Collection

Soil nutrient sampling was conducted monthly during the growing season in 1986 at the ground, antenna and control sites. In 1985 the hardwoods were sampled monthly, while the plantations were sampled only once in July. After initial success in using soil nutrients in the hardwood growth models, it was decided that sampling in the plantations would also be conducted monthly in successive years to provide soil nutrient data for the red pine growth analysis. Twenty randomly selected samples per plot were collected using a push probe inserted to a depth of 15 cm. Samples were then composited to 5 per plot and analyzed for Kjeldahl N, total P, and exchangeable Ca, Mg, and K.

Progress

Average monthly nutrient content values were generally greater in the hardwood stands at the control than at the antenna site for nearly all sampling dates in 1985 and 1986 (Table 14, Appendix B). In addition, the 1985 values are

higher than in 1986 for both the hardwood stands and the plantations (Table 15, Appendix B) and may be due to greater organic matter content in the 1985 samples. Loss on ignition will be run on these samples in the coming year to determine organic matter content to help explain these differences.

Hardwood Stands

Analysis of variance was conducted to test differences between various soil nutrient levels from the hardwood stands and sites, years, and months (Table 1.22) Results varied depending upon the nutrient and factor tested but in general, significance levels were higher for sites than for years.

Table 1.22. Significance levels from the analysis of soil nutrients in 1985 and 1986.

HARDWOODS

	Ca	Mg	K	P[b]	N
Site	.072	.036	.029	-	.221
Year	.000	.852	.000	-	.000
Site by year	.043	.252	.044	-	.047
Month	.108	.573	.014	-	.000
Month by site	.084	.456	.190	-	.007
Month by site by year	.003	.406	.082	-	.081

PLANTATIONS[a]

	Ca	Mg	K	P[b]	N
Site	.069	.233	.017	-	.109
Year	.000	.000	.000	-	.000
Site by year	.045	.096	.153	-	.048

[a] Plantations were sampled in July only in 1985, therefore analysis by month was not conducted.

[b] Anova for P was not conducted due to differences in laboratory methods between 1985 and 1986.

Potassium was used as a covariate in the hardwood productivity studies and has been the most important soil nutrient in terms of explaining growth differences between sites and years. Significant differnces (p=0.05) were found for potassium

between sites, years, months, and the site by year interaction (Table 1.22). This is the only nutrient in which all of these factors are significantly different and may indicate why potassium has been so effective as a covariate.

Red Pine Plantations

July was the only month in 1985 in which sampling was conducted on the red pine plantations. As a result soil nutrients were tested only with site and year factors in the analysis of variance. Significant differences ($p=0.05$) between sites were found for potassium only while significant differences exist for all nutrients between years. In addition, the site by year interaction was non significant for all nutrients. Potassium has also been an important covariate in the red pine growth analysis which may be explained by the significant differences that exist in sites and years.

Future work will focus on determining organic matter content to help explain spatial and temporal variability in soil nutrient levels. In addition, the relationship between soil nutrients and litter production, and northern red oak nutrition will be investigated. Finally, work will continue using soil nutrients as covariates in the hardwood and red pine growth studies.

ELEMENT 2. TREE PRODUCTIVITY

Tree growth is sensitive to a variety of environmental disturbances. In order to detect any changes in growth due to site disturbance, accurate tree measurements are essential. The most widely accepted tree growth measurements are diameter at breast height outside bark (dbh) and height. Of these two growth variables, height is the more difficult to measure on mature trees. The installation of permanent dendrometer bands on the stem of a tree allows measurement of minute changes (0.008 cm) in diameter over a short time interval (Husch et al. 1982). Two additional advantages in using dbh as a measurement of tree growth are the responsiveness of cambial activity to environmental effects (Smith 1986) and the strong correlation between dbh and total biomass of the tree (Crow 1978). Consequently, measurement of diameter increment is the primary response variable for assessing the effects of ELF fields on hardwood stand growth. Tree height was used for initial stand characterization.

While dbh and height measurements can provide information on present stand production and a means to predict future productivity, the capacity of a stand to continue producing is also examined by monitoring tree reproduction and mortality. Stand structure (the distribution of trees by diameter classes) changes from year to year due to natural growth, reproduction, and mortality of trees. Any environmental disturbance could produce an effect on these factors. Therefore, to achieve a complete picture of possible ELF effects on tree and stand production, dbh, height, ingrowth, and mortality are being measured in order to distinguish natural changes from those caused by site disturbances.

In addition to tree productivity in hardwood stands, regeneration studies involving planted red pine seedlings are being conducted on the ground, antenna, and control sites. These studies were initiated in response to a need for a larger number of conifers in the ectomycorrhizal studies (Element 6) as well as to address the Michigan DNR concerns about forest regeneration. Since young trees often exhibit more rapid growth rates compared to older trees, possible ELF field effects on these seedlings may be more easily detected here rather than on older trees. In the red pine seedlings, both diameter and height increment are response variables for assessing any possible effects due to ELF fields. Again, as in the case of trees in the hardwood stands, diameter, height, and mortality are being measured.

Hardwoods

Diameter increment is the primary response variable for assessing effects of ELF fields on the hardwood stands located on the antenna and control sites. Permanently installed

dendrometer bands allow continual measurements of incremental growth on each tree in the stand. This information provides a view of both the total growth in an entire growing season and the rate or distribution of diameter growth over the growing season.

Hardwood stands on both study sites are classified in the Acer-Quercus-Vaccinium habitat type (Coffman et al. 1983). Those species common to both sites and included in the analysis are northern red oak (Quercus rubra), paper birch (Betula papyrifera), bigtooth aspen (Populus grandidentata), quaking aspen (Populus tremuloides), and red maple (Acer rubrum). A summary of stand information for both sites can be found in Table 2.1; the change in average dbh on the study sites for each year since 1984 is given in Table 2.2.

Each analysis will eventually test the overall null hypothesis:

> H_0: There is no difference in the level or the pattern of seasonal diameter growth before and after the ELF antenna becomes operational.

This hypothesis is actually addressed by testing for differences between the control and the antenna sites and by testing for differences between post-operational years and previous years. Since the system operated at low levels (15 amps) throughout the 1987 growing season, differences between sites and between 1987 and previous years are examined in the following analyses. Tests of rate or distribution of diameter growth are made using the diameter growth model discussed later in this section. Differences in the parameters of the growth model between years and sites will also be examined to test the above hypothesis. This test for differences in growth model parameters indicates whether or not different seasonal growth patterns are occurring on the different sites. Differences in the level or amount of seasonal diameter increment are examined through the split plot analysis of covariance. The analysis of covariance table used in this study is found in Table 2.3.

Sampling and Data Collection

To monitor diameter growth at both sites, permanent dendrometer bands were installed in 1984 on all trees greater than or equal to 10 cm at dbh. Due to vandalism, 175 new bands were installed on the control site in 1985. On the antenna site the number of study trees was reduced from 209 in 1984 to 197 in 1985 due to a few band failures and a small vandalism incident unrelated to that on the control site. The death of one bigtooth aspen on the control site reduced that sample to 274 trees in 1985. At the start of the 1987 growing season, the trees which had band failures and suffered vandalism in 1985 on the antenna site, as well as all trees which had become larger than 10 cm in dbh since 1984, were banded on both sites (Table 2.1). This gave a total of 214

Table 2.1. Summary of hardwood stand information for the antenna and control sites at the beginning of the 1987 growing season.

Species	Average DBH (cm)[B/]	Basal Area Per Hectare (m^2/ha)	Number Bands in 86	Number Bands in 87	Number of Stems per Hectare	Site Index	Age (yrs)
Antenna							
Northern Red Oak	23.58	7.78	44	49	167	68	47
Paper Birch	20.56	.92	8	8	25	66	55
Aspen[A/]	25.67	2.60	15	15	48	68	50
Red Maple	15.18	8.57	129	142	457	56	42
Control							
Northern Red Oak	20.95	20.86	174	175	559	72	52
Paper Birch	16.36	2.88	40	40	127	60	54
Aspen	23.03	6.00	44	44	139	65	55
Red Maple	11.69	.60	15	18	57	58	45

A/ The two aspen species are combined.
B/ Average DBH includes ingrowth trees for 1987.

Table 2.2. Average dbh (cm) by species and site at the beginning of each year of this study.[A]

	1984	1985	1986	1987	1988[B]
Antenna					
Northern Red Oak	22.18	22.45	22.69	23.09	23.36
Paper Birch	20.02	20.22	20.42	20.56	20.70
Aspen[C]	24.59	25.01	25.37	25.67	25.93
Red Maple	14.87	15.09	15.23	15.33	15.44
Control					
Northern Red Oak	20.45	20.62	20.82	20.94	21.12
Paper Birch	16.12	16.23	16.30	16.36	16.41
Aspen	22.21	22.55	22.82	23.03	23.18
Red Maple	11.37	11.64	11.85	12.01	12.17

A/ Only trees banded prior to 1987 are represented here.
B/ Values given for the beginning of the 1988 growing season were calculated by adding all previous years growth to diameter taken in 1984.
C/ The two aspen species are combined.

Table 2.3. ANOVA table used for analysis of diameter growth by species.

Source of Variation					
Covariate	Group (A)	# group A covariates	SSC	MSC	MSC/MSE(S)
Site		1	SSS	MSS	MSS/MSE(S)
Error(S)		# trees-2-#covariates	SSE(S)	MSE(S)	
Years		# years-1	SSY	MSY	MSY/MSE(SY)
Site x Years		(1)(#years-1)	SSSY	MSSY	MSSY/MSE(SY)
Covariate	Group (B)	# group B covariates	SSCY	MSCY	MSCY/MSE(SY)
Error(SY)		(#trees-2-#covariates)(#yrs-1)	SSE(SY)	MSE(SY)	

Group A covariates differ by site but not by year, such as soil characteristics.
Group B covariates change from year to year, such as annual rainfall.

banded trees on the antenna site and 277 banded trees on the control site.

Bands were read to the nearest 0.01 inches of circumference at both study sites beginning on April 8 in an attempt to insure monitoring of diameter growth initiation. Weekly readings continued until September 30 when growth had slowed considerably and over 50 percent of leaf fall had taken place. This provided a total of 26 measurements in 1987.

Progress

Growth Analysis

Levels and rates of diameter increment were examined for each species. Due to a lack of differences between size classes in previous years (Mroz et al. 1986), analyses of differences in growth rate or pattern between size classes were not made in 1987.

Analysis of tree diameter increment is approached in two ways. The split plot analysis of covariance is used to determine if there is any change in the level of average yearly diameter growth due to ELF fields. Secondly, regression models are being developed to further quantify the relationships between tree, site, and climatic variables and tree diameter growth. These models are used to test for changes in both seasonal growth pattern within a year and relationships affecting total annual growth due to ELF fields. The modeling analyses use information for trees banded since 1985. The split plot analysis of covariance only utilizes growth information on trees which have been banded for the entire study period.

Analysis of Total Seasonal Diameter Growth

At present, four years (1984, 1985, 1986, and 1987) of diameter increment data have been collected from trees on the study sites. In 1984, first incremental growth was not collected until early June due to a relocation of the control site. Because of this, total diameter increment in 1984 is not derived from dendrometer band data, but from spring and fall diameter tape measurements of individual trees. Also, due to installation and calibration of the ambient monitoring equipment, the climatic variables are not completely available for 1984. For these reasons, the 1984 diameter growth measurements were not included in the split plot analysis of covariance. Table 2.4 presents the total annual diameter growth by species for each of the four growing seasons, even though data from 1984 were not included in the following analyses.

Following the 1986 growing season, a small study was conducted to compare the growth rates on the study plots to

Table 2.4. Average seasonal diameter growth (cm) for tree species on each site for the 1984, 1985, 1986, and 1987 growing seasons.[A/]

	Sample Size	1984	1985	1986	1987
		---------------	---------------	cm	---------------
Northern Red Oak					
Antenna	44	0.2778	0.2389	0.1991	0.2710
Control	174	0.1707	0.2030	0.1508	0.1823
Paper Birch					
Antenna	8	0.2000	0.2038	0.1500	0.1304
Control	40	0.1050	0.0765	0.0652	0.0406
Aspen					
Antenna	15	0.4133	0.3653	0.2993	0.2355
Control	44	0.3386	0.2643	0.2164	0.1529
Red Maple					
Antenna	129	0.2163	0.1374	0.1017	0.1130
Control	15	0.2667	0.2040	0.1533	0.1768

[A/]Only trees banded prior to 1987 are represented here.

that of trees in the surrounding stand. The growth rate had declined on the study plots from 1984 to 1986 and this study was undertaken to determine if the measurement activity could have caused this decline or if the decline was also present in the surrounding stand. The results (Appendix D) indicate that the growth declines were not confined to the study plots and there was no indication that the measurement activity was affecting the total seasonal diameter growth rates on the study plots.

Analysis of annual diameter growth on the study plots began with an intensive variable screening procedure to select covariates to include in the split plot analysis of covariance. Correlations between each of the tree, site, and climatological variables and average plot diameter growth were calculated. The average plot growth for each species was used in the screening procedure to remove the effect of tree to tree variation within a plot. During the covariate screening, a group of similar variables (such as soil temperature degree days at the two depths and air temperature) were often similarly correlated with the growth rate for a species. In this case, the most highly correlated variable within the group was selected for further analysis for the species. This allowed the selection of covariates which were as independent of each other as possible. Table 2.5 contains the covariates selected for each species and the corresponding correlation coefficients. For some species, a variable which did not show a high correlation with growth was still an important covariate because it helped explain site or year differences when considered together with the other covariates.

The results of the split plot analysis of covariance for each species are given in Table 2.6. The analysis of covariance was performed using the individual tree measurements with the tree's diameter at the beginning of the 1984 growing season as a covariate in addition to the variables in Table 2.5. The potassium concentrations were not used as a covariate in the results in Table 2.6 since the 1987 nutrient concentrations were not yet available.

From Table 2.6, there were no detectable differences ($p=0.05$) in diameter growth rates between the antenna and control sites for any species but, for every species except paper birch, there were significant ($p=0.05$) differences in the diameter growth rates between years. There were no significant ($p=0.05$) interactions between sites and years for any species. This implies that, even though the growth rates between years were significantly different, the relationships between the growth rates on the two sites were relatively constant over the three years (1985, 1986, and 1987). Thus, there is no evidence from this analysis that the diameter growth rates for 1987, when the ELF system was undergoing low power testing, showed any different relationships between the antenna and control sites than were observed in previous years. Even though the growth rates differed between years, the relative differences between sites were consistent across the years. The observed differences between years and the

Table 2.5. Correlations between the covariates selected for inclusion in the analysis and hardwood plot average diameter growth rates by species.

Covariate	Species Northern Red Oak	Paper Birch	Aspen[A/]	Red Maple
Soil Temperature Degree Days at 5 cm (through July)	-.49	--	--	-.06
Air Temperature Degree Days (through September)	--	-.69	-.86	--
Water Holding Capacity	--	--	-.38	.66
Potassium Concentration (PPM) in June[B/]	.26	--	--	--
Potassium Concentration (PPM) in July[B/]	--	-.21	-.06	.48

[A/] The two aspen species were combined for this analysis. Plot 2 on the antenna site, which only has a single aspen tree, was not included in this analysis.

[B/] Sample data for 1987 were not yet available so these results only include data from 1985 and 1986.

Table 2.6. Significance levels from the split plot analysis of covariance for each species.

Factor	Species: Northern Red Oak	Paper Birch	Aspen	Red Maple
Site	0.64	0.64	0.97	0.43
Years	0.00[A/]	0.19	0.01	0.00
Site x Years	0.20	0.19	0.45	0.86

[A/] A significance level smaller than 0.05 indicates a significant difference between years (p=.05).

detection limits for annual differences are given by species in Table 2.7. There were differences between 1985 and 1986 for northern red oak, aspen, and red maple. The growth in 1987 was different (p=0.05) from each of the previous years for aspen and red maple and different from 1986, but not 1985, for northern red oak.

To examine these differences, an analysis was performed using data from only 1985 and 1986 which included potassium concentration as a covariate. For each of these three species, potassium concentration accounted for the differences in growth observed between 1985 and 1986. From Element 1, potassium concentration in the soil is significantly different (p=.05) between sites and between years and the potassium deposited by rainfall is significantly different between years. Soil nitrogen differs between years, but not between sites, and it is uncorrelated with growth. From Element 7, there are significant differences in potassium and phosphorus concentrations in the litter for red maple and northern kred oak, but potassium is the only nutrient which differs between sites in the green red oak foliage. There are therefore, differences in potassium levels between years and sites which are reflected in several types of vegetation analyses; this is not true for any other nutrient being examined in the study. When the nutrient concentrations are available for 1987, the split plot analysis of covariance will be repeated for each species and will include potassium concentration as a covariate. Given the results of 1985 and 1986, this may account for the statistical differences between years in the current analysis.

Diameter Growth Model

Many of the relationships between diameter growth and tree, site, and climatic variables can be expected to be nonlinear (Spurr and Barnes 1980, Kimmins 1987). These nonlinear relationships cannot be accounted for in the split plot analysis of covariance described above. In order to supplement the split plot analysis of covariance, diameter growth models for each of the four species are being developed to further account for variability in growth between sites and over years. Since the seasonal pattern of diameter growth as well as total annual growth could be subject to ELF field effects, the weekly cumulative diameter growth (cm) was selected as the response variable.

Differences in diameter growth observed since 1985 include differences in the timing of growth between sites, differences in timing between species, and differences in the amounts of growth between years (Mroz et al. 1986). Since the stand conditions did not change drastically since 1985, these observed diameter growth differences are likely due to physiological differences between species, climatic differences between years, and physical differences between sites. By breaking cumulative diameter growth into the

Table 2.7. Comparisons of differences in hardwood diameter growth rates between years for each species.

Limits[A]/ Species (%)	Years 1985	 1986	 1987	Detection (cm)	
Northern Red Oak 5.6	A[B]/	B	A	.010	
Paper Birch .6	A	A	A	.016	20
Aspen 8.4	A	B	C	.020	
Red Maple 5.9	A	B	C	.007	

[A]/The detection limits given are for between year differences (p=0.05) between adjusted means where the limits are expressed in cm and as a percent of average growth across all years.

[B]/Different letters indicate years with significantly different (p=0.05) growth rates for a species.

component parts of total annual growth and proportion of total growth completed by the date of observation, the effect of tree, site, or climatic variables on each of these diameter growth components can be examined. This also simplifies the testing for significant effects of ELF fields on tree diameter growth. Cumulative diameter growth to time t is therefore represented by:

$$CG_t = (\text{Total Annual Growth})\ (\text{Proportion of Growth to time t})$$

The above formulation allows the testing of ELF field effects on both the level of total annual growth (TAG) and the pattern of seasonal growth. In the model, total annual growth is further broken into the component parts of physiological potential growth, the effect of intertree competition, and the effect of site physical, chemical, and climatic properties:

$$TAG = (\text{Physiological Potential Growth})(\text{Intertree Competition})\\ (\text{Site Physical, Chemical, and Climatic Properties})$$

Each of these components, and the seasonal growth pattern component, are discussed below. To date, exploratory analyses are being conducted on the components representing intertree competition and site physical, chemical, and climatic effects. The components representing physiological potential growth and seasonal growth pattern are subject to modification as more data become available.

Physiological Potential Growth

Results from previous years (Mroz et al. 1985, 1986) indicated that the model form given by Botkin et al. (1972) for representing physiological potential growth showed the most promise on these study sites, but that it needed to be recalibrated for these specific sites. The physiological potential growth (PPG) is represented by:

$$PPG = \frac{G\ D\ (1 - DH/D_{MAX}H_{MAX})}{274 + 3\ b_2\ D - 4\ b_3\ D^2}$$

where D is tree DBH, H is tree height, D_{MAX} and H_{MAX} are the maximum observed tree diameter and height, respectively, for a species, and G, b_2, and b_3 are constants to be estimated.

Estimated coefficients for this model were given in previous years (Mroz et al. 1985, 1986). Differences (p=0.05) in the estimated coefficients were observed between years, but not between sites within a year. It was observed that these differences were probably due to the model form inadequately accounting for year to year variation in growth due to climatic conditions and variation within a site due to intertree competition. This led to the developmental work on the two model components representing the effects of intertree

competition and site physical, chemical, and climatic properties on diameter growth. Because of these past results, comparisons were not made on the estimated coefficients of this model component between sites in 1987 or between 1987 and previous years. These comparisons will be made following further progress on formulating the growth model components representing intertree competition and the effects of site physical, chemical, and climatic conditions on diameter growth.

Intertree Competition

Following estimation of the growth model coefficients in 1986, it was found that the area potentially available to each tree (Brown 1965) was significantly ($p=0.05$) correlated with the residuals from the growth model (Mroz et al. 1986). This indicated that the model was not adequately accounting for the effects of spacing and competition from neighboring trees on individual tree diameter growth. For this reason, efforts were undertaken to develop a diameter growth model component which would represent the effects of intertree competition on diameter growth. The effects of competition and spacing are largely independent of soil physical, chemical, and climatic properties of a site. Any variation in annual diameter growth explained by this component should, for the most part, be in addition to that explained by the other model components.

Efforts to date have concentrated on evaluating numerous competition indices (Appendix E) on the study sites as is detailed below. It is possible that intertree competition will involve different environmental factors for each species. For instance, aspen is probably primarily affected by competition from neighboring trees for light while red maple may be more influenced by competition for moisture or nutrients. For this reason, the methods eventually chosen for measuring competition for use in the growth model may differ by species. For each of the species though, it is expected that there will be little impact on individual tree diameter growth if the individual is under low levels of competition. As competition increases, the impact on diameter growth is expected to increase rapidly and then level off at high levels of competition. The effect of intertree competition (IC) could be represented in the growth model by utilizing an individual tree competition index (CI), where the index itself may vary by species, in the following form:

$$IC = e^{-(a_1 CI)}$$

Following evaluation of numerous competition indices for each species, this model form and possibly others representing the above expected effects of this component will be tested in the overall growth model for each species.

There were five indices tested which represent the competitive effect of surrounding trees on the subject tree. They include an index developed by Lorimer (1983), one by Daniels et al. (1986), one by Hegyi (1974), and two by Spurr (1962). Competition has also been expressed as the amount of influence zone overlap (Opie 1968) where influence zones are defined as the area in which a tree competes for elements in the environment. The two overlap indices examined are by Bella (1971) and Arney (1973). Several versions of area potentially available (APA) were also evaluated. In this index, half the distance to a neighboring tree is assumed to be available for the subject tree's use. If a perpendicular line is drawn at this point, for all neighboring trees, a closed polygon will result. The area of this polygon is the APA (Brown 1965). The indices developed under this assumption which were examined include one by Moore et al. (1973), one by Pelz (1978), and one by Nance et al. (1987).

Correlations with annual diameter growth were performed on each index and modifications of each index described above. Indices with consistently high correlations ($p<.0001$) by species and across all years and sites are listed in Table 2.8. As was expected, different indices performed better for different species. Lorimer's index performed best for all species except aspen. This index is the sum of the ratio of diameters of the competitors and the subject tree. This can be thought of as indicating the relative resource requirements of the subject tree and its competitors. For aspen, Bella's index had the greatest correlation with diameter growth. Bella's index involves estimates of crown diameter and it's overlap with that of neighboring trees. This primarily represents light availability and, since aspen is the most shade intolerant species in the study, it is not surprising that this index is most highly correlated with aspen growth. The indices listed in Table 2.8 are currently being evaluated for inclusion in the overall diameter growth model.

Site Physical, Chemical, and Clima'ic Factors

As discussed above with the split plot analysis of covariance, using site physical and climatic factors accounted for a large amount of the variation in diameter growth rates between sites for each of the four species. For paper birch, these factors also accounted for the observed variation in diameter growth between years. When only 1985 and 1986 are considered, the additional use of soil potassium concentration (ppm) in June or July accounted for much of the year to year variation in diameter growth for the remaining species. When the soil analyses are completed for the 1987 samples, tests will be made to see if this is true for all three years considered together.

The split plot analysis of covariance essentially uses linear regression to remove the variation due to the covariates. An underlying assumption is that the covariates

Table 2.8. Competition indices significantly correlated ($p<.0001$) with annual growth by species across all years and sites.

Source of Index	Plot Radius, Weighting, etc.	Index Form[B/]	Northern Red Oak	Paper Birch	Aspen[A/]	Red Maple
Lorimer (1983)	7.62 m	$\sum_{j=1}^{n} D_j/D_i$	-.64	-.75	--	-.56
Hegyi (1974)	7.62 m	$\sum_{j=1}^{n} \frac{D_j/D_i}{L_{ij}}$	-.53	-.54	--	-.44
Bella (1971)	ex = 1	$\sum_{j=1}^{n} [(a_{ij}/A_i)(D_j/D_i)^{ex}]$	-.55	--	--	-.54
Bella (1971)	ex = 3	$\sum_{j=1}^{n} [(a_{ij}/A_i)(D_j/D_i)^{ex}]$	--	--	-.50	--
Arney (1973)	---	$\left(\frac{\left(\sum_{j=1}^{n} a_{ij}\right) + A_i}{A_i}\right) 100$	--	--	--	-.46
Brown (1965) and Nance (1987)	Weighted APA	---	.60	--	--	--

A/ The two aspen species are combined

B/ D_i - Subject tree DBH
D_j - Competitor tree DBH
L_{ij} - Distance between competitor and subject tree.
n - Number of competitors in a plot
a_{ij} - Area of influence zone overlap between competitor and subject tree
A_i - Area of subject tree influence zone
Weighted APA - Distance to perpendicular line between two trees is weighted by $\frac{D_i}{D_i+D_j}$

are linearly related to the response variable, which in this case is the annual diameter growth. Figures 2.1, 2.2, 2.3, and 2.4 illustrate the relationships between the plot average diameter growth rates and the covariates selected previously. Some of these appear to be linear relationships, such as the relationship between seasonal total air temperature degree days and paper birch growth, while others appear to be nonlinear, such as the relationship between the soil water holding capacity and red maple growth. The effects of these different site physical and climatic variables on diameter growth are probably not independent. An illustration of this can be seen in the relationships between soil temperature degree days through July and diameter growth for northern red oak and red maple. For these two species, growth decreased from 1985 to 1986 as degree days increased, but increased from 1986 to 1987 as degree days increased further. This is probably due to the effect of additional moisture on the sites during the 1987 growing season compared to previous years (Figure 2.5). While the final formulation of this component will follow from further analysis, an initial formulation accounting for the linear relationships could be as follows:

$$SPCC = \frac{(D + b_1 X_1 + b_2 X_2 + \ . \ . \ . + b_k X_k)}{D}$$

where SPCC is the model component representing the effect of site physical, chemical, and climatic conditions, D is tree diameter at the beginning of the growing season, X_i, i = 1, 2, . . ., k, are the site properties affecting growth for a given species, and b_i, i = 1, 2, . . ., k are the coefficients to be estimated. This is a preliminary model form which, based on the results of the split plot analysis of covariance, could be expected to significantly improve the overall model's ability to estimate diameter growth. Alternative formulations will be evaluated in the future.

Seasonal Growth Pattern

As was the case in previous years (Mroz et al. 1986), the cumulative air temperature degree days to time t was the most important variable affecting the seasonal diameter growth pattern of all four species on both sites. The model form developed in 1986 relating proportion of growth completed by time t to air temperature degree days is given by:

$$PG_t = 1 - e^{-(ATDD_t/b)^c}$$

where PG_t is the proportion of total annual diameter growth completed by time t, $ATDD_t$ is the cumulative air temperature

Figure 2.1. Relationships between plot average diameter growth rates for northern red oak and significant site physical, chemical, and climatic factors. Observations connected by a solid line are from the same plot in different years.

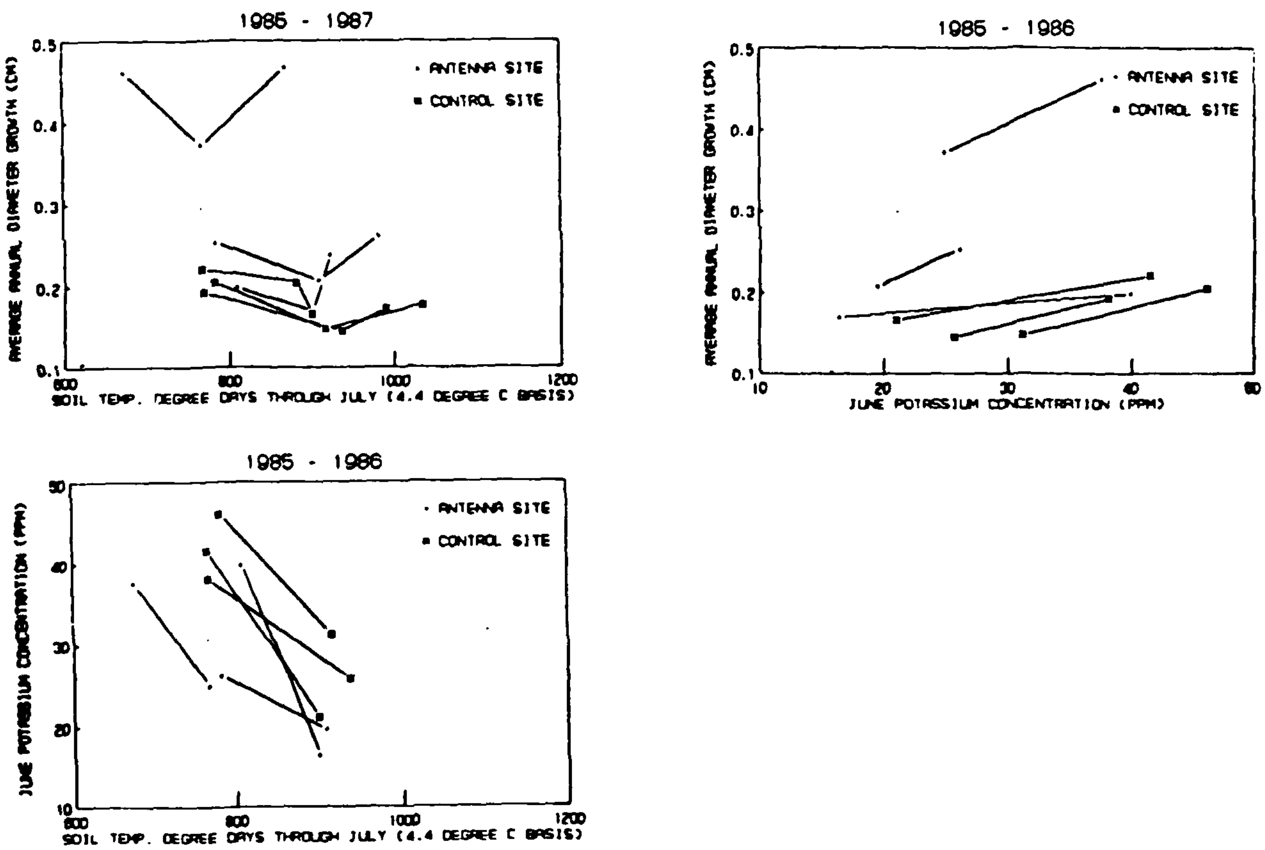


Figure 2.2. Relationships between plot average diameter growth rates for paper birch and significant site physical, chemical, and climatic factors. Observations connected by a solid line are from the same plot in different years.

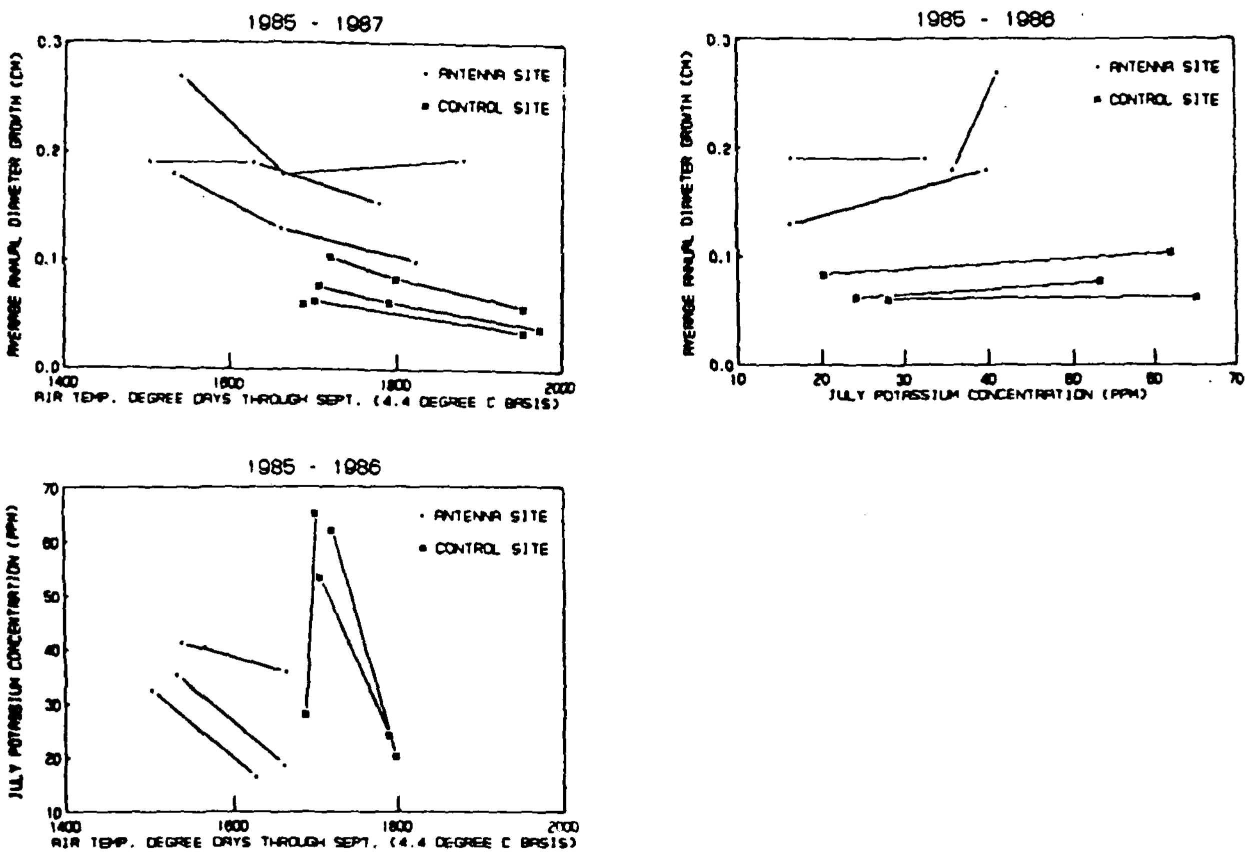


Figure 2.3. Relationships between plot average diameter growth rates for aspen and significant site physical, chemical, and climatic factors. Observations connected by a solid line are from the same plot in different years.

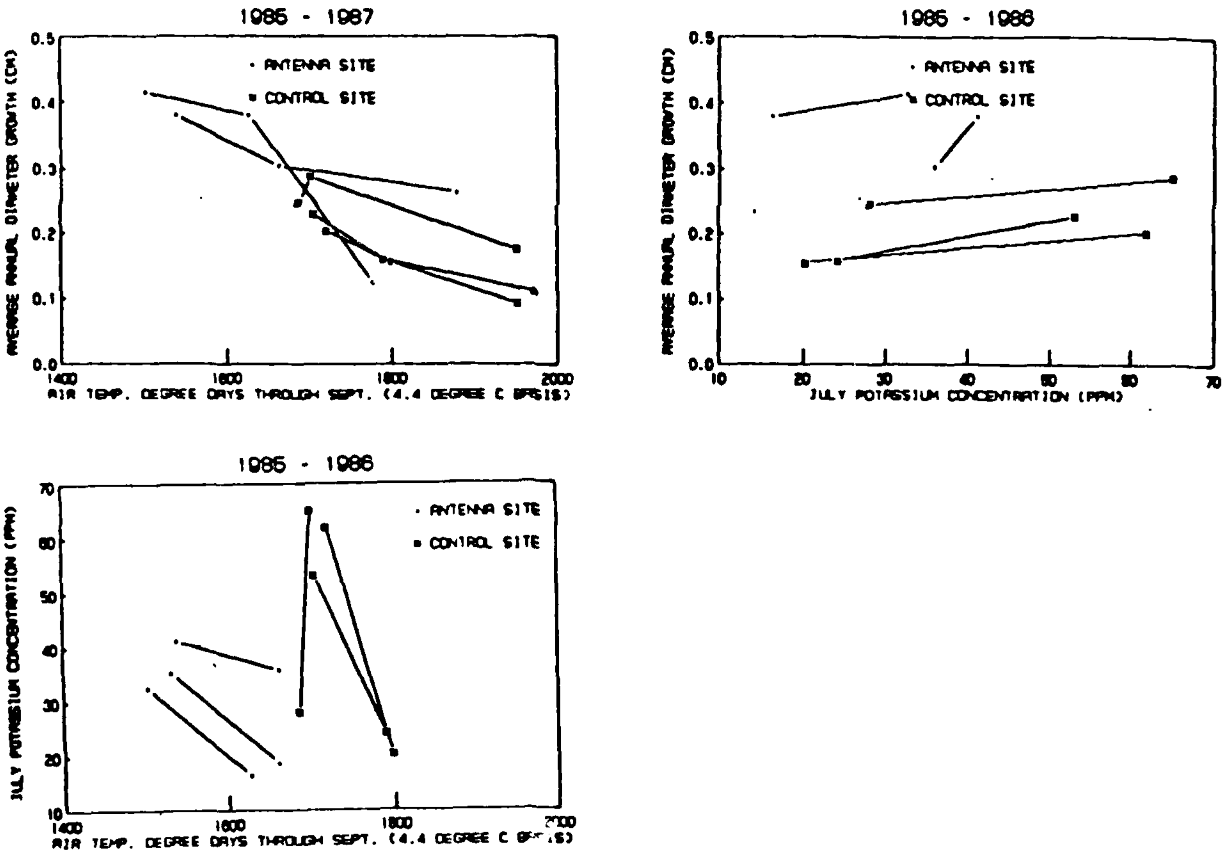


Figure 2.4. Relationships between plot average diameter growth rates for red maple and significant site physical, chemical, and climatic factors. Observations connected by a solid line are from the same plot in different years.

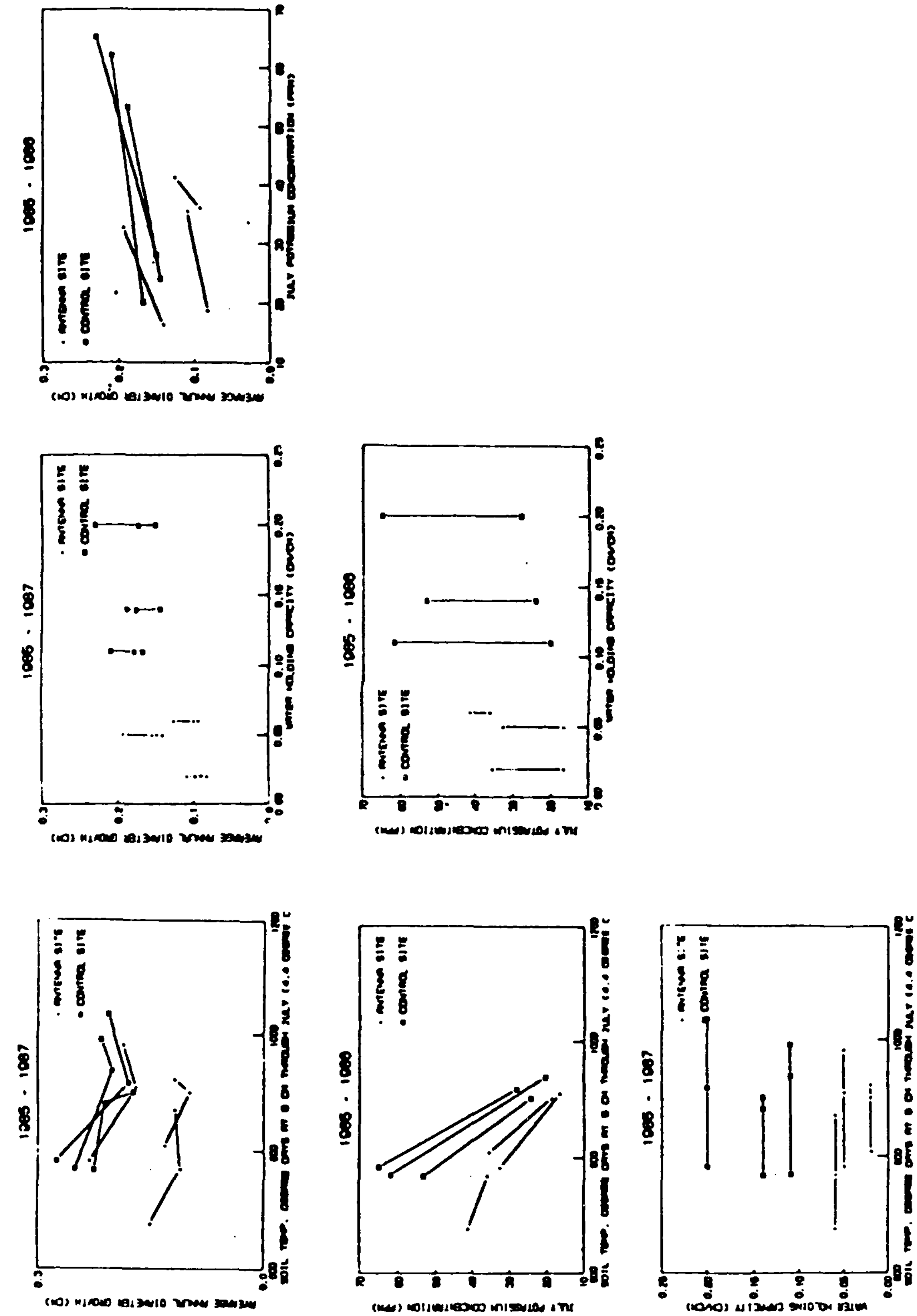
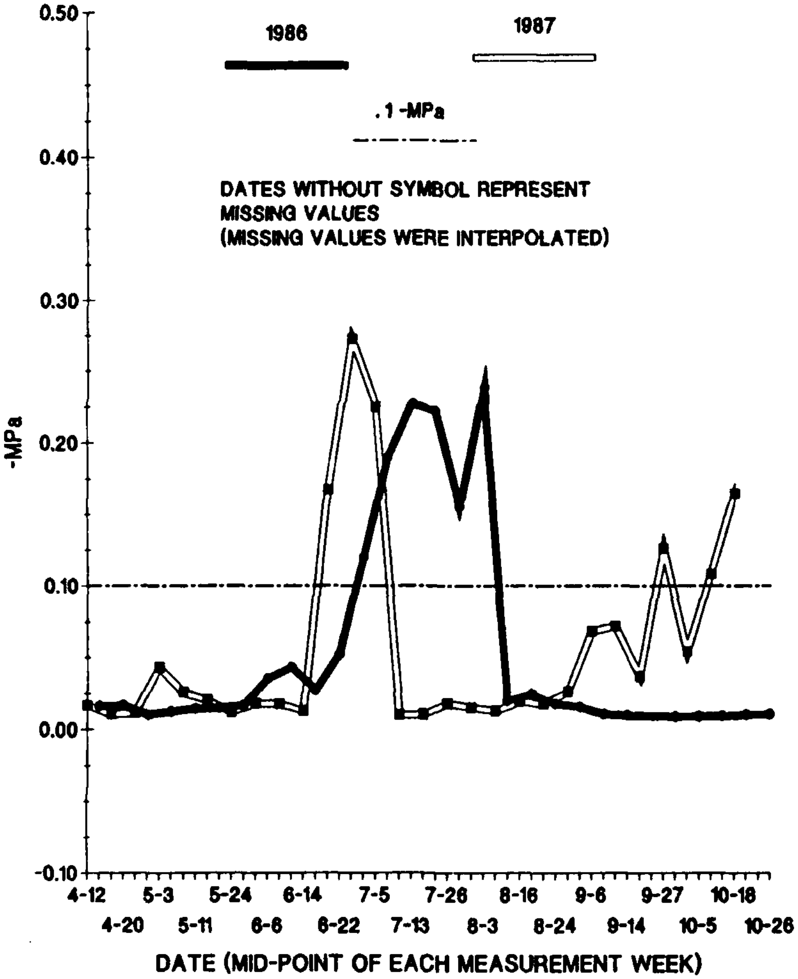
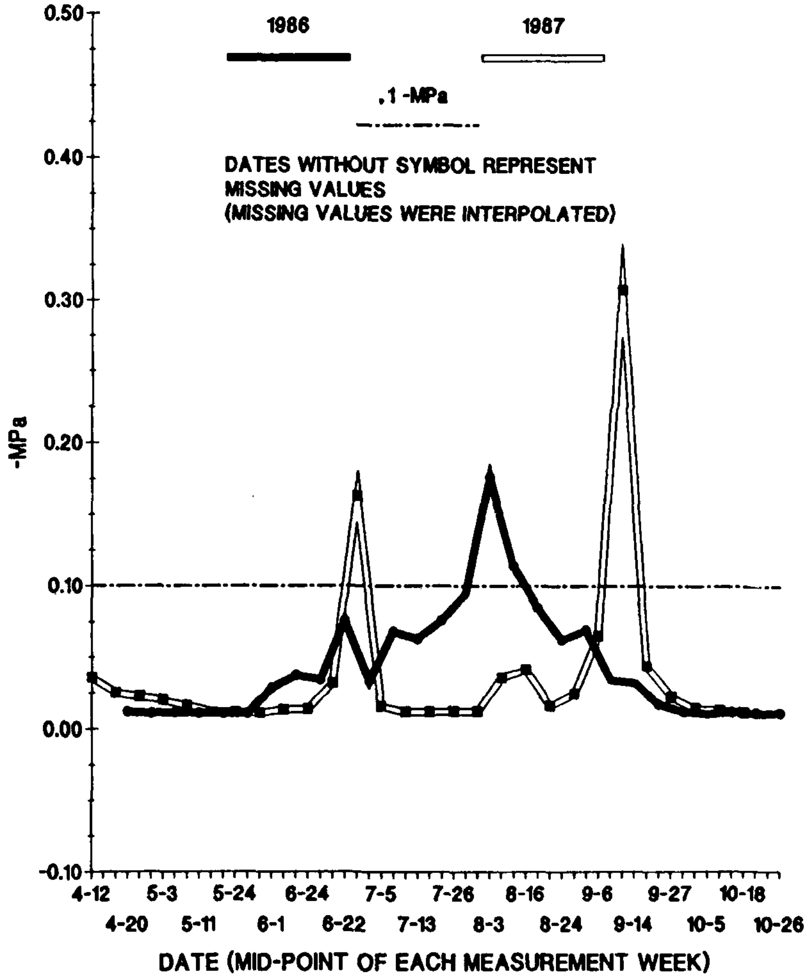


Figure 2.5

SOIL MOISTURE TENSION AT DEPTH OF 10 CM.
ANTENNA HARDWOOD STANDS
1986-1987



SOIL MOISTURE TENSION AT DEPTH OF 10 CM.
CONTROL HARDWOOD STANDS
1986-1987



degree days to time t, b and c are constants to be estimated for each species.

As in 1985 and 1986, there were no detectable differences ($p=0.05$) in the coefficients of the seasonal growth pattern component between sites for any species in 1987. This suggests that there were no significant ($p=0.05$) changes in the seasonal diameter growth pattern for any species attributable to the low level testing of the antenna system during the 1987 growing season. Some differences between years for northern red oak and red maple did exist, but they were consistent over the sites. There were some changes in the estimated coefficients which were consistent across both the antenna and the control sites between 1987 and the two previous years. For northern red oak, the estimated c coefficient was different ($p=0.05$) on the control site between 1986 and 1987, for aspen the estimated b coefficient was different ($p=0.05$) on the antenna site in 1987 compared to the control site in 1985, and for red maple, there were differences in both estimated coefficients from those in previous years.

According to the compensation principle (Zeide 1980), species highly adapted to a shortage of one environmental factor, such as light, can be expected to be less tolerant of shortages of other factors, such as moisture. This may be the reason that more differences in growth patterns between years were noted for red maple, the most shade-tolerant species in the study, than the other three species. Figure 2.6 illustrates the differences in the estimated seasonal diameter growth pattern and Figure 2.7 illustrates the estimated proportions of annual diameter growth completed during different months of the growing season for red maple on the antenna site in 1986 and 1987. Given the differences in soil water potential during the middle of the growing season between 1986 and 1987 (Figure 2.5), the above results may indicate that diameter growth of some of these species, especially red maple, may have been affected by moisture levels. Equivalent low moisture levels appear to impact growth differently at different times of the growing season. Current efforts are investigating various methods of incorporating soil water potential into the formulation of the seasonal growth pattern component of the overall diameter growth model.

Red Pine

Seedling Growth

Since young trees experience rapid growth rates, possible effects on growth due to ELF electromagnetic fields may be more easily detected on seedlings rather than on older more slowly growing individuals. Other justifications for investigating red pine seedlings are: 1) the response to

Figure 2.6

ESTIMATED 1986 AND 1987 RED MAPLE ANNUAL GROWTH PATTERNS
ANTENNA SITE

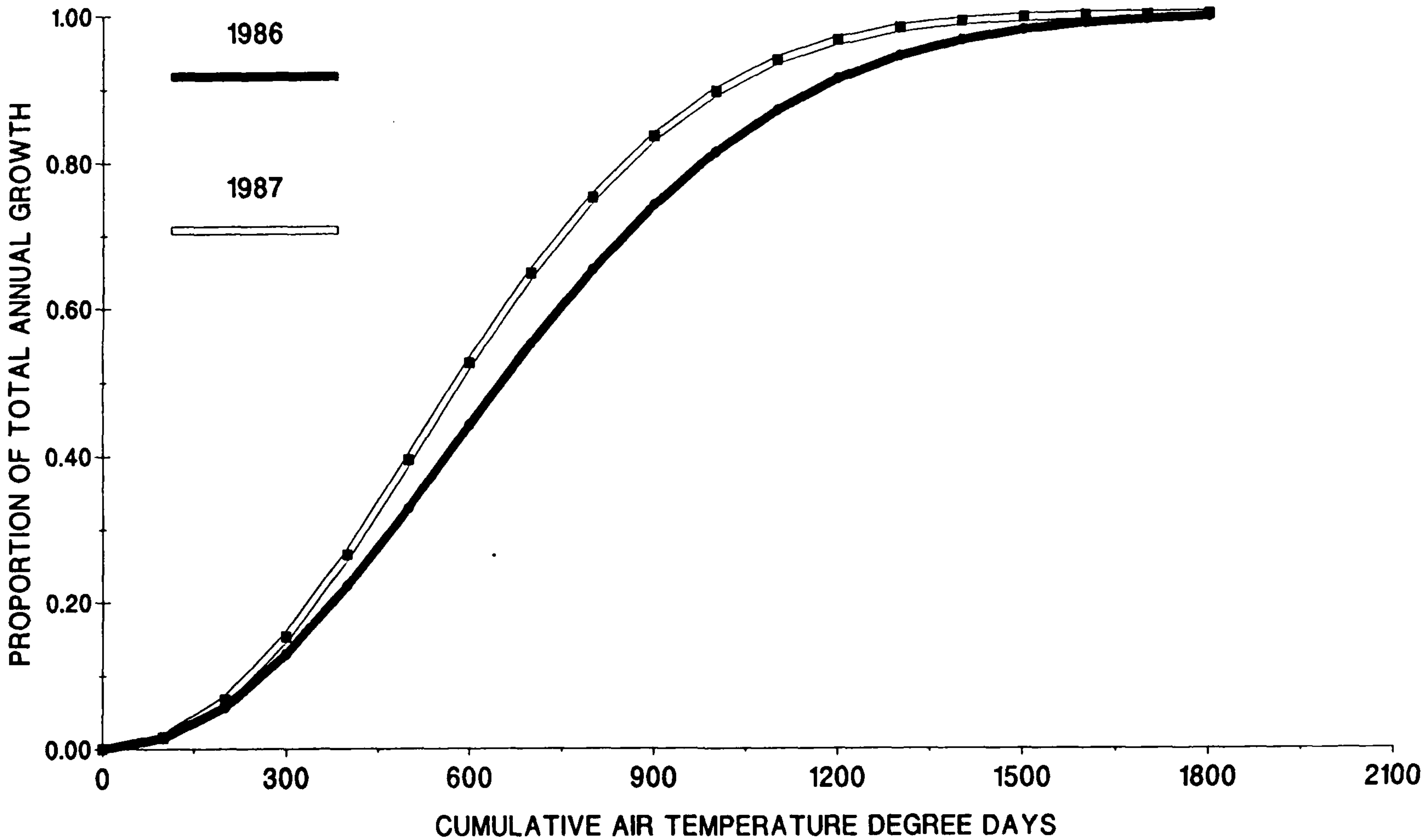
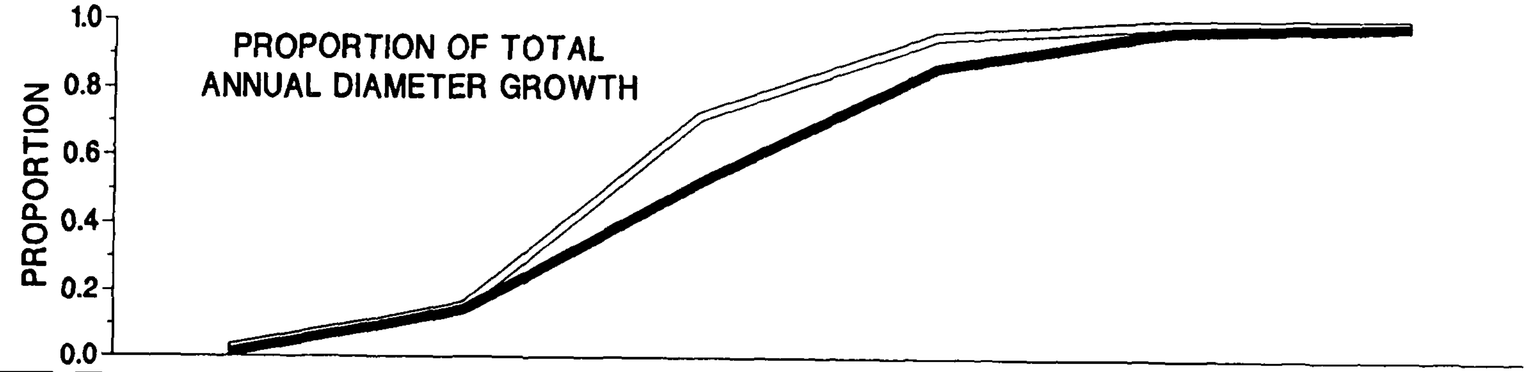
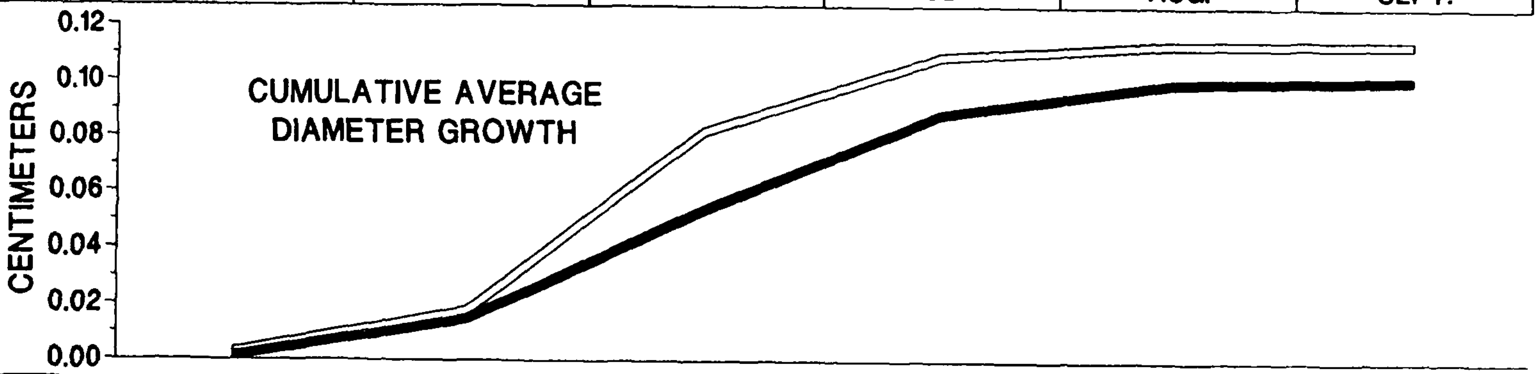


Figure 2.7

ESTIMATED 1986 AND 1987 RED MAPLE SEASONAL GROWTH PATTERNS OVER TIME ON THE ANTENNA SITE



	APRIL	MAY	JUNE	JULY	AUG.	SEPT.
1986	.012	.144	.523	.863	.977	.991
1987	.025	.155	.719	.957	.998	1.000



	APRIL	MAY	JUNE	JULY	AUG.	SEPT.
1986	.0012	.0147	.0534	.0880	.0997	.1011
1987	.0028	.0177	.0819	.1090	.1137	.1139

Michigan DNR concerns over effects on forest regeneration, 2) the lack of sufficient natural conifer regeneration on the study sites for mycorrhizal studies, and 3) the magnetic fields associated with the antenna ground rapidly decrease over a short distance. Thus, construction of the antenna ground through a red pine plantation allows the study trees to be closer to the electromagnetic source than would any mature tree plot which requires a buffer strip of trees along the right-of-way.

Total height (cm) and basal diameter (cm) increment on the red pine seedlings are the response variables for assessing possible ELF electromagnetic field effects. Measurements made weekly (on seedling height only) and seasonally (seedling height and diameter) allow examination of both the total growth in a growing season as well as the distribution of growth within the season. This study is conducted on the ground, antenna, and control sites. A summary of stand information for the three study sites can be found in Table 2.9. Changes in average diameters and heights at each study site over the length of the study are found in Table 2.10.

The evaluation of red pine seedling growth is divided into two areas: 1) the determination of annual growth, vigor, and survival, and 2) the evaluation of seedling growth patterns as a function of time. The overall null hypotheses tested in this phase of the study are:

> H_0: There is no difference in the level of seasonal diameter growth of planted red pine seedlings before and after the ELF antenna becomes operational.

and

> H_0: There is no difference in the level or the pattern of seasonal height growth of planted red pine seedlings before and after the ELF antenna becomes operational.

As discussed earlier in the hardwood stand analyses, evaluation of possible ELF electromagnetic fields on height growth is approached in two forms: the level of height growth in a growing season is analyzed through the split plot analysis of covariance while the pattern of height growth within a growing season is described through a height growth model. Each of these analyses examines possible site differences as well as any existing differences between pre-operational and post-operational years. The analysis of covariance table used is the same as that found in the hardwood studies (Table 2.3). The level of diameter growth in a growing season will only be analyzed through the split plot analysis of covariance.

Sampling and Data Collection

Small areas at the antenna, ground, and control sites were whole-tree harvested in the spring of 1984. These areas were immediately planted with 3-0 stock red pine seedlings at

Table 2.9. Summary of red pine stand information for the ground, antenna, and control sites at the end of the 1987 growing season.

Site	Sample Size	Average DBH (cm)	Average Height (cm)	Average Bud Size (mm)
Ground	141	1.880	59.19	19.90
Antenna	177	2.117	66.55	22.27
Control	199	2.116	69.85	23.67

Table 2.10. Average diameter (cm) and height (cm) for each site at the end of each year of this study.

	Diameter (cm)	Height (cm)
Ground		
1984	0.450	17.18
1985	0.743	22.73
1986	1.280	37.33
1987	1.880	59.19
Antenna		
1984	0.441	16.80
1985	0.701	23.92
1986	1.262	40.34
1987	2.117	66.55
Control		
1984	0.459	18.96
1985	0.792	28.33
1986	1.355	50.50
1987	2.116	69.85

a 1 m by 1 m spacing. This density would provide adequate numbers of seedlings for destructive sampling throughout the study period, allow for natural mortality, and leave a fully stocked stand when the study is completed. Following planting, 300 seedlings at each site were randomly selected and permanently marked for survival and growth studies. Additional details concerning the establishment of the red pine plantations can be found in past reports (Mroz et al. 1985, 1986).

Natural mortality following the first full growing season (1985) was 43 percent at the ground site, 37 percent at the antenna site, and 28 percent at the control site. This mortality was somewhat high due to the late planting date resulting in planting shock as well as desiccation of seedlings during handling and planting. In addition, Mroz et al. (1988) observed that 61 percent of the apparently healthy seedlings that did not form terminal buds following planting died, which further indicates the inability of some seedlings to adapt to the planting site. Precipitation during 1985 was adequate for seedling establishment and competition around each seedling was minimal. It is unlikely that these factors had a significant effect in causing this mortality.

The mortality that occurred in 1985 was not evident in 1986 or 1987. Only a few seedlings died during the course of the last two growing seasons. In 1985 the number of permanently marked seedlings was reduced from 300 to 170 at the ground site, 188 at the antenna site, and 217 at the control site. In 1986, these numbers were further reduced to 147 seedlings, 184 seedlings, and 211 seedlings, respectively. Mortality during the 1987 field season resulted in a drop in samples to 141 seedlings at the ground site, 177 seedlings at the antenna site, and 199 seedlings at the control site.

Vegetative recovery following whole-tree harvesting in 1984 increased in 1986. This vegetation competed with the red pine seedlings for physical resources such as moisture, nutrients, and light. Vegetation control was necessary in 1986 to prevent the competing vegetation from affecting the unrestricted growth of the seedlings. In early June, 1986, competing vegetation was mechanically removed from each plantation plot using gas powered weed-eaters equipped with brush blades. This method was successful in releasing over-topped seedlings and essentially eliminating competition in 1986. In early June 1987, we found sufficient carryover effect to suggest that it was not necessary to repeat weed control again this year.

For red pine growth analysis, each of the live permanently marked seedlings on each site were measured at the end of the growing seasons in 1984, 1985, 1986, and 1987, and the following information recorded:

basal diameter (cm)
total height (cm)
terminal bud length (mm)
microsite

physical damage
presence of multiple leaders
number of neighboring seedlings

Information on microsite, physical damage, multiple leadered seedlings, and the number of neighboring seedlings was collected for possible use in explaining results of the growth analyses. Microsite described the physical environment in the immediate vicinity of the seedling such as rocky soil surface, proximity to a stump, or proximity to skid trails. Any physical damage to a seedling such as frost or animal damage was also recorded. Some seedlings possess two or more leaders, none of which expressed dominance over the others and this situation was noted as well. In addition, beginning in 1987, the number of seedlings surviving in neighboring planting spacings was also recorded to aid in describing any future competition for light and moisture between neighboring seedlings that might occur.

To further describe the growth of the red pine seedlings, a subsample of 100 seedlings per site was selected from the permanently marked seedlings for weekly height growth measurements. These weekly measurements were obtained in 1985, 1986, and 1987. Measurements began in mid-April and continued until mid-July when shoot elongation was completed. Measurements were made from the center of the previous year's whorl to the meristematic tip or tip of the new terminal bud.

Progress

Growth Analysis

The two response variables in this segment of the study are height and diameter increment of red pine seedlings. Differences in total seasonal height or diameter increment from site to site or from year to year are analyzed through the split plot analysis of covariance where tree, site, and monthly averages of climatological data are used as covariates. The pattern of growth during the growing season is depicted through a growth model that has been developed for height increment only. The coefficients of the height growth model are compared from site to site and from year to year to examine possible differences in the rate at which height growth is achieved each year at each site.

Total Annual Height and Diameter Growth

Separate split plot analyses of covariance examined any existing differences in either seasonal height or diameter increment among the three sites as well as from year to year. At this point there are three years of growth measurements available (1985, 1986, and 1987). The average seasonal growth

for each of these response variables on each site at the end of each growing season is found in Table 2.11.

Prior to the split plot analyses of covariance, correlations were calculated between tree, site, monthly averages of climatological data, and average plot values for height and diameter increment. Both the current seasonal climatic information as well as the previous year's seasonal climatic information with respect to a year's height or diameter growth were considered in the correlation analysis. Because climatic information was not collected in 1984, the correlation matrix for growth and the previous year's climatic data includes only 1986 and 1987 growth information combined with 1985 and 1986 climatic information, respectively. The correlation matrix of growth with current climatic data examines 1985, 1986, and 1987 data.

Those variables having the highest correlations with either height or diameter growth were considered for use as covariates in the split plot analysis of covariance. Generally, similar climatic variables (such as air temperature degree days and soil temperature degree days at 5 and 10 cm) had similar correlation values; thus, only the highest correlated variable was incorporated into later analyses to insure as much independence between the covariates as possible. The tree, site, and climatic variables selected for inclusion in the covariance analysis together with their respective correlations are found in Table 2.12.

Use of the previous year's monthly climatic data explained more site and yearly variation than the current year's data. This was true for both height and diameter increment. For this reason only growth occurring in 1986 and 1987 have been included in the analyses. Incorporating the height measurement of the seedling in 1985, the average air temperature in July, the average minimum daily air temperature in May, and the average maximum daily air temperature in June led to nonsignificant ($p=0.05$) differences in height growth among the three study sites as well as between the years 1986 and 1987 (Table 2.13). This indicates no detectable effect on the height growth from the low levels of ELF fields during the 1987 field season.

Site and yearly differences were also explained by covariates in the analysis of diameter increment. In this case the covariates selected included the diameter of the seedling in 1984, rooting volume as a percent of total soil volume (excluding rocks and other material > 2 mm), soil moisture at 10 cm in the month of June, average minimum daily air temperature in July, and average maximum daily air temperature in May (Table 2.12). Again the low level ELF fields occurring in 1987 appear to have had no detectable ($p=0.05$) effect on the average seasonal diameter growth of the red pine seedlings (Table 2.13).

Reduction of detection limits on both response variables was also achieved through the analysis. The ability to detect a difference in height growth among the three sites improved 16 percent from the limits detectable without the use of

Table 2.11. Average seasonal diameter growth (cm) and height growth (cm) for each site for the 1985, 1986, and 1987 growing seasons.

	1985	1986	1987
Diameter Growth (cm)			
Ground	0.27	0.53	0.60
Antenna	0.23	0.55	0.86
Control	0.32	0.57	0.76
Height Growth (cm)			
Ground	5.08	14.28	23.75
Antenna	6.61	16.06	26.96
Control	8.34	22.34	31.87

Table 2.12. Correlations between covariates selected for inclusion in the analysis and red pine plot averages of diameter growth (cm) and height growth (cm).[A/]

Covariate	Diameter Growth	Height Growth (cm)
Diameter in 1984 (cm)	.13	--
Height in 1985 (cm)	--	.55
Rooting Volume (%)	-.47	--
Air Temperature in July[B/]	--	.84
Soil Moisture at 10 cm in June	-.32	--
Minimum Average Daily Temperature in May	--	-.62
Minimum Average Daily Temperature in July	.67	--
Maximum Average Daily Temperature in May	.70	--
Maximum Average Daily Temperature in June	--	.91
Seasonal Soil Temperature Degree Days at 10 cm	.76	--

[A/]Growth values are for 1986 and 1987 only.
[B/]Climatic data is from the previous year.

Table 2.13. Significance levels from the split plot analysis of covariance for diameter growth (cm) and height growth (cm).

Factor	Diameter Growth (cm)	Height Growth (cm)
Site	.5488[A/]	.5697
Year	.5504	.1406
Site x Year	.0590	.2706

[A/] A significance level smaller than 0.05 would indicate significance (p=0.05).

covariates; the detection limits improved 4 percent for diameter growth. The detection limits from year to year did not drop for height growth, but dropped 1 percent for diameter growth. The current detection limits on both response variables are found in Table 2.14.

The use of the previous year's climatic data provides results that are consistent with the fact that red pine is a species of deterministic growth. Height growth in any year is strongly related to the size of the terminal bud which was formed under the previous year's climatic and ambient conditions (Kozlowski et al. 1973). Thus, the low level ELF electromagnetic fields had no significant effect on the total seasonal height or diameter growth on the red pine seedlings since there were no differences among the sites in 1987 or between study years.

Seasonal Pattern of Height Growth

To evaluate changes that might occur in the pattern or timing of height growth among the three study sites or from year to year, height growth models were developed to predict cumulative height growth at a given point in the growing season. The model is a modified Weibull function of the form:

$$h_t = b_0 + (1 - e^{-b_1 \, ATDD_t})^{b_2}$$

where h_t is the proportion of the total annual height growth completed by time t, $ATDD_t$ is the total accumulation of air temperature degree days (4.4^{o} C basis) during the current growing season to time t, and b_0, b_1, and b_2 are coefficients to be estimated. Except for b_0, which estimates an actual amount of height growth which has occurred before measurements begin each season, the other two coefficients merely relate to properties of plant growth. The duration of growth during the season, whether it is drawn out or very brief, is related to the coefficient b_1. The timing of growth or the skewness of the growth curve is related to the coefficient b_2.

This form of the equation and the use of air temperature degree days as the independent variables is similar to work completed by Perala (1985). Previous work in this study incorporated time as the independent variable (Mroz et al. 1986), but greater consistency has been found in coefficient estimates using current season climatic information. The climatic data also provide information to explain natural site variations that do exist. Accumulated soil temperature degree days at 5 cm and 10 cm have been examined, but the performance of these models did not improve over that of the above model using air temperature degree days.

As mentioned earlier, there are now three seasons of height growth measurements (1985, 1986, and 1987). The coefficients for the growth model were estimated for each site (ground, antenna, and control) in each growing season. Using

Table 2.14. Detection limits expressed in centimeters and as percent of average growth.

	Factor	
	Site	Year
Detection Limit (cm)		
Diameter Growth	0.06	0.03
Height Growth	1.70	0.59
Detection Limit (%)		
Diameter Growth	9.2	4.6
Height Growth	7.4	2.6

the subsample of weekly height measurements, the proportion of total annual height growth achieved by time t was the dependent variable. Each seedling's height growth at a given week is considered to be an observation. Forty percent of the total number of observations on a given site in a given year were randomly selected for use in validating the height growth models and were not used in the estimation process.

The three coefficients were estimated for each of the three sites during the 1985, 1986, and 1987 growing seasons using the developmental data sets. To evaluate the equations the average residual, the standard deviation of the residuals, and the proportion of variation explained were calculated as in previous years (Mroz et al. 1986). These statistics are given in Table 2.15.

The proportion of variation explained ranges from 0.92 in 1985 up to 0.97 in 1987 across all three sites indicating a relatively precise estimate of seasonal height growth. The ranges of average residuals were quite small in any given year at any given site suggesting unbiased estimates as well.

Combining the two data sets and re-estimation of coefficients gave the final models. Final estimates of the coefficients and confidence intervals about the estimates are given in Table 2.16. The models explain 90 to 92 percent of the variation in the system in 1985, 94 to 96 percent of the variation in 1986, and 98 to 99 percent of the variation in 1987. Examples of the predicted versus the observed height growth curves for each site in 1987 are found in Figures 2.8, 2.9, and 2.10.

Among the three sites during any given year there were few significant differences in the respective estimates of the coefficients. This is illustrated in the predicted growth curves for 1987 found in Figure 2.11. In 1987, there was a significant difference ($p=0.05$) in the intercept (b_0) for the control compared to the other two sites. The seedlings at the control site did not seem to begin growing as quickly as those on the other two sites. The coefficients b_1 and b_2 for the ground site were significantly different ($p=0.05$) from the other two sites in 1987. Though seedlings at the ground site initially grew at about the same rate as seedlings at the other two sites, they grew at a slower rate later in the season.

In 1986 only one coefficient was significantly different ($p=0.05$). At the control, b_2 was significantly different from the respective coefficient for the other two sites. Growth at the three sites began similarly, but seedlings at the control site tended to grow slower for the rest of the season. Differences in coefficient estimates for 1985 were similar to those in 1987. At the control, b_0 was significantly different ($p=0.05$) from the other two sites since the seedlings were slower in initial growth. At the ground, the estimates of b_1 are significantly different from the other two sites while the estimates of b_2 differ over all three sites. These differences in 1985 can be partially attributed to the carryover of planting shock in 1984 as well as possible site

Table 2.15. Performance of the height growth equations for red pine seedlings on the ground, antenna, and control sites during the 1985, 1986, and 1987 growing seasons.

	Average Residual (cm) A/	Standard Deviation of Residuals	Proportion of Variation Explained B/
1987			
Ground	.0030	.0436	.9747
Antenna	-.0007	.0377	.9769
Control	-.0025	.0379	.9763
1986			
Ground	-.0014	.0572	.9469
Antenna	.0020	.0486	.9655
Control	.0011	.0409	.9730
1987			
Ground	.0150	.0691	.9121
Antenna	-.0105	.0682	.9260
Control	.0007	.0676	.9167

A/ Residual= (Observed value - Predicted value)

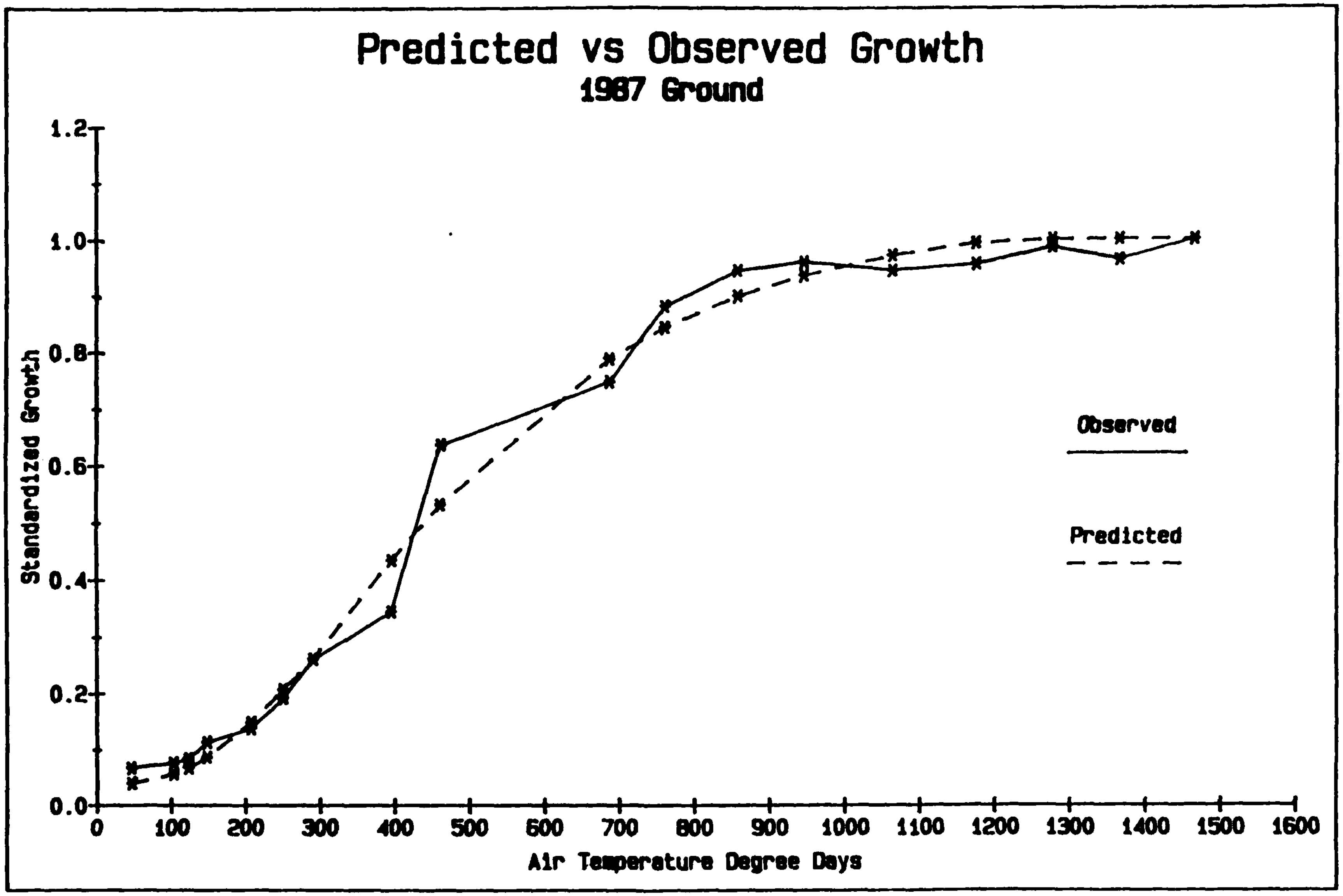
B/ Proportion of Variation Explained = $\dfrac{\sum_n (y_i-\bar{y})^2 - \sum_n (y_i-\hat{y}_i)^2}{\sum_n (y_i-\bar{y})^2}$

where y_i = observed value, $\hat{y}_i$ = predicted value, and $\bar{y}$ = average value

Table 2.16. Estimates of the three coefficients b_0, b_1, b_2, for the height growth equations on the ground, antenna, and control sites during the 1985, 1986 and 1987 growing seasons.

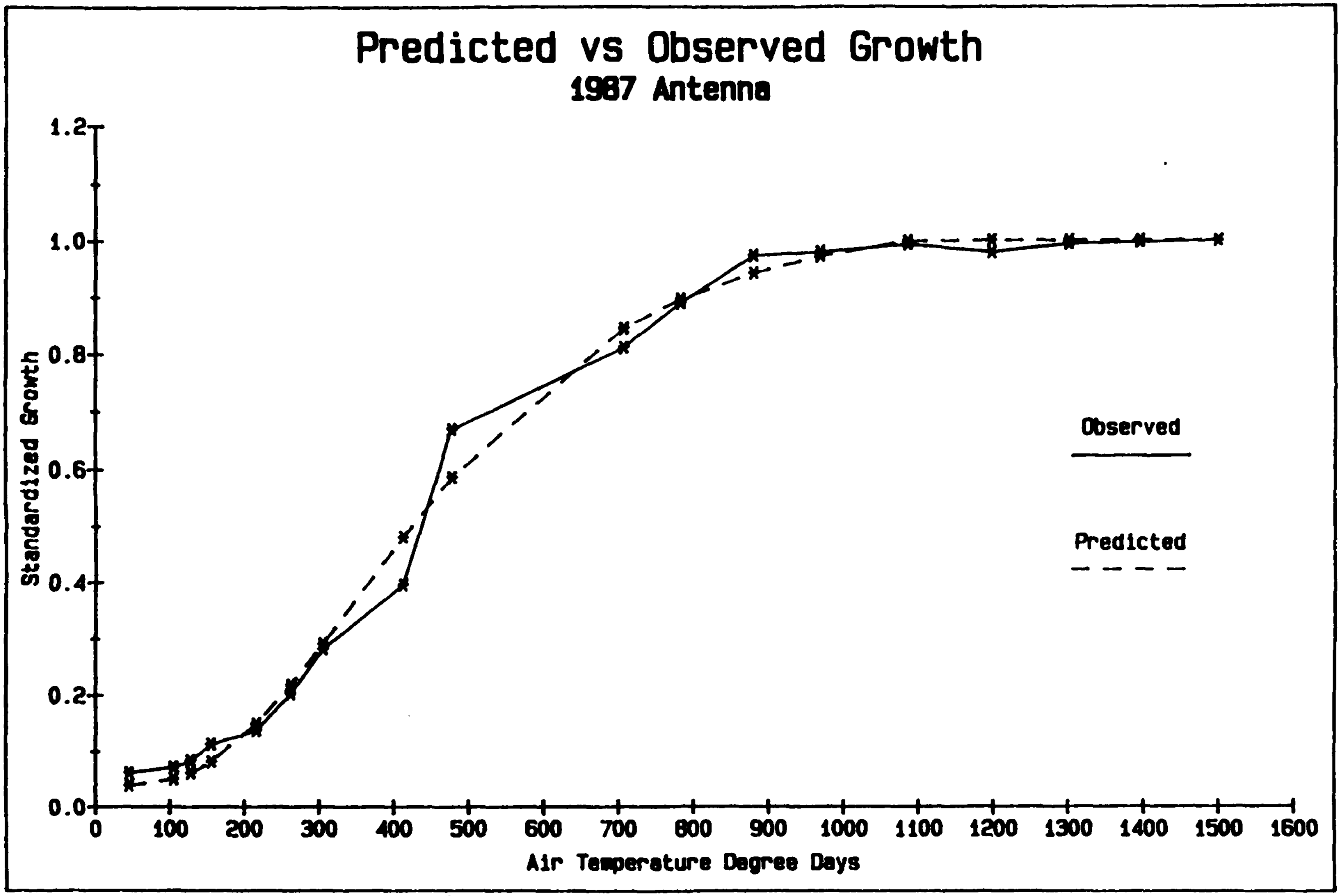
	b_0	Asymptotic 95% Confidence Interval	b_1	Asymptotic 95% Conficende Interval	b_2	Asymptotic 95% Confidence Interval
1987						
Ground	0.0385	(.0327, .0443)	0.0037	(.0036, .0038)	3.5187	(3.3538, 3.6839)
Antenna	0.0391	(.0347, .0435)	0.0043	(.0041, .0044)	4.3902	(4.1935, 4.5884)
Control	0.0257	(.0213, .0301)	0.0045	(.0043, .0046)	4.4353	(4.2158, 4.6354)
1986						
Ground	0.0321	(.0187, .0369)	0.0068	(.0066, .0071)	4.0435	(3.6939, 4.1839)
Antenna	0.0417	(.0358, .0457)	0.0064	(.0062, .0066)	3.9195	(3.7126, 4.1273)
Control	0.0375	(.0323, 0.426)	0.0069	(.0066, .0071)	5.1878	(4.9066, 5.4669)
1985						
Ground	0.0596	(.0471, .0721)	0.0035	(.0033, .0037)	2.3565	(2.2055, 2.5078)
Antenna	0.0448	(.0374, .0521)	0.0054	(.0052, .0056)	4.0129	(3.7302, 4.2932)
Control	0.0188	(.0117, .0259)	0.0059	(.0056, .0061)	4.9869	(4.5875, 5.3842)

Figure 2.8



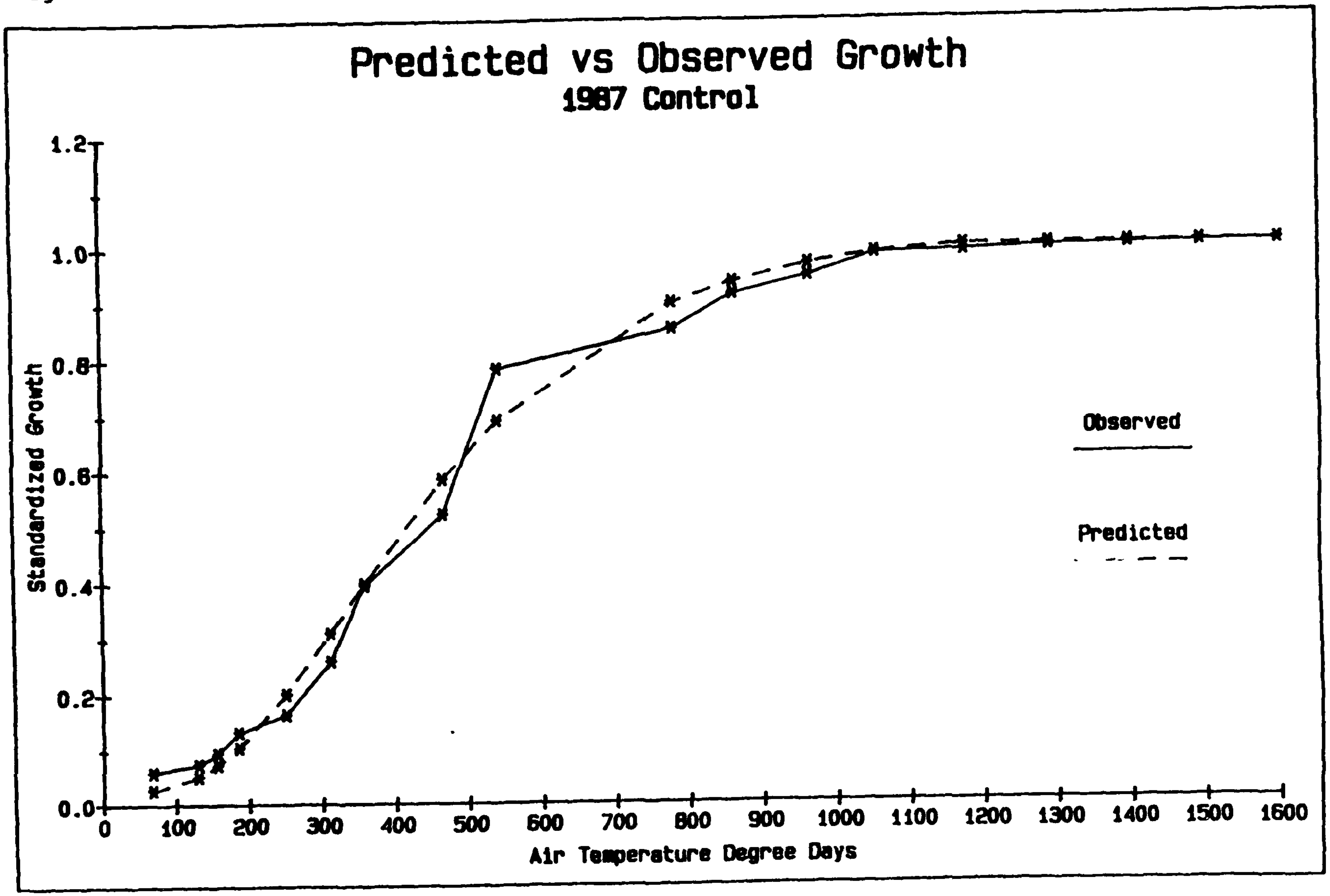
Predicted vs Observed Growth
1987 Ground
Standardized Growth
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
Air Temperature Degree Days
Observed
Predicted

Figure 2.9



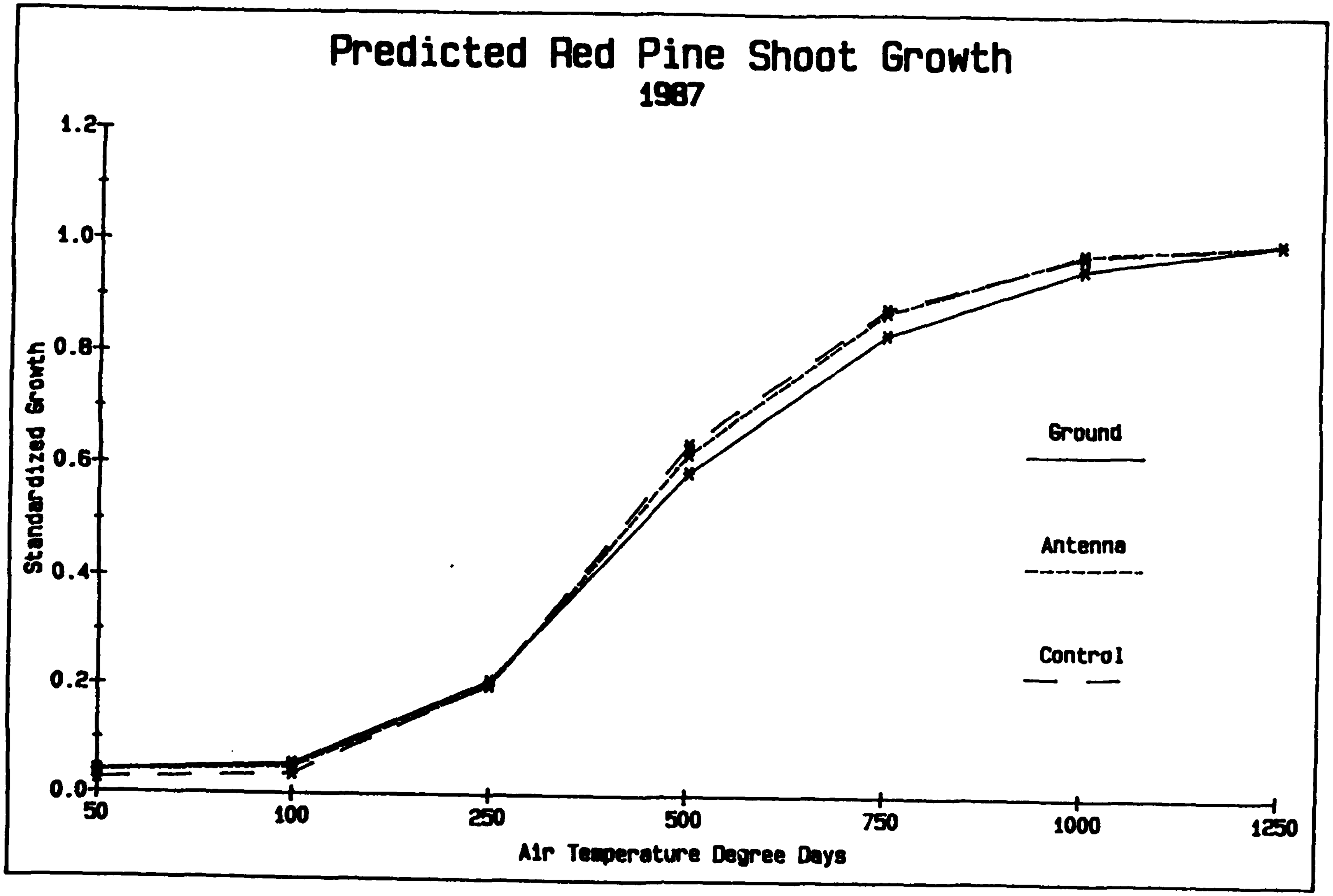
Predicted vs Observed Growth
1987 Antenna
Standardized Growth
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
Air Temperature Degree Days
Observed
Predicted

Figure 2.10



Predicted vs Observed Growth
1987 Control
Standardized Growth
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
Air Temperature Degree Days
Observed
Predicted

Figure 2.11



Predicted Red Pine Shoot Growth
1987
Standardized Growth
0.0
0.2
0.4
0.6
0.8
1.0
1.2
50
100
250
500
750
1000
1250
Air Temperature Degree Days
Ground
Antenna
Control

variation that has not yet been accounted for in the model formulation.

There are significant changes in the coefficients from one growing season to another. The pattern of the height growth curves differ from 1985 to 1986 to 1987, but they seem to differ similarly at each site (Figures 2.12, 2.13, and 2.14). It appears that a given proportion of accumulated height growth was achieved with fewer accumulated air temperature degree days in 1986, followed by 1985; finally in 1987 more accumulated air temperature degree days are required for any given proportion of accumulated height growth. Because there are significant differences in the coefficients from year to year, at this point the effect or lack of effect of low level ELF fields in 1987 cannot be fully determined.

These significant differences in coefficients suggest that more variation in the natural system needs to be accounted for. As discussed earlier in the hardwood growth analyses, redpine seedling height growth may be impacted by low moisture levels. Differences in soil water potential during the growing season between 1986 and 1987 may contribute to existing variation in the system (Figures 2.15, 2.16, and 2.17). For example, the slow initial growth of seedlings at the control in 1987 may have been impacted by the low moisture levels that existed at the site early in the growing season. Future work will address these possibilities and model refinement will follow. Secondly, though intertree competition does not exist at this point in time, the future possibility of including this factor will need to be examined as well.

Red Pine Foliage

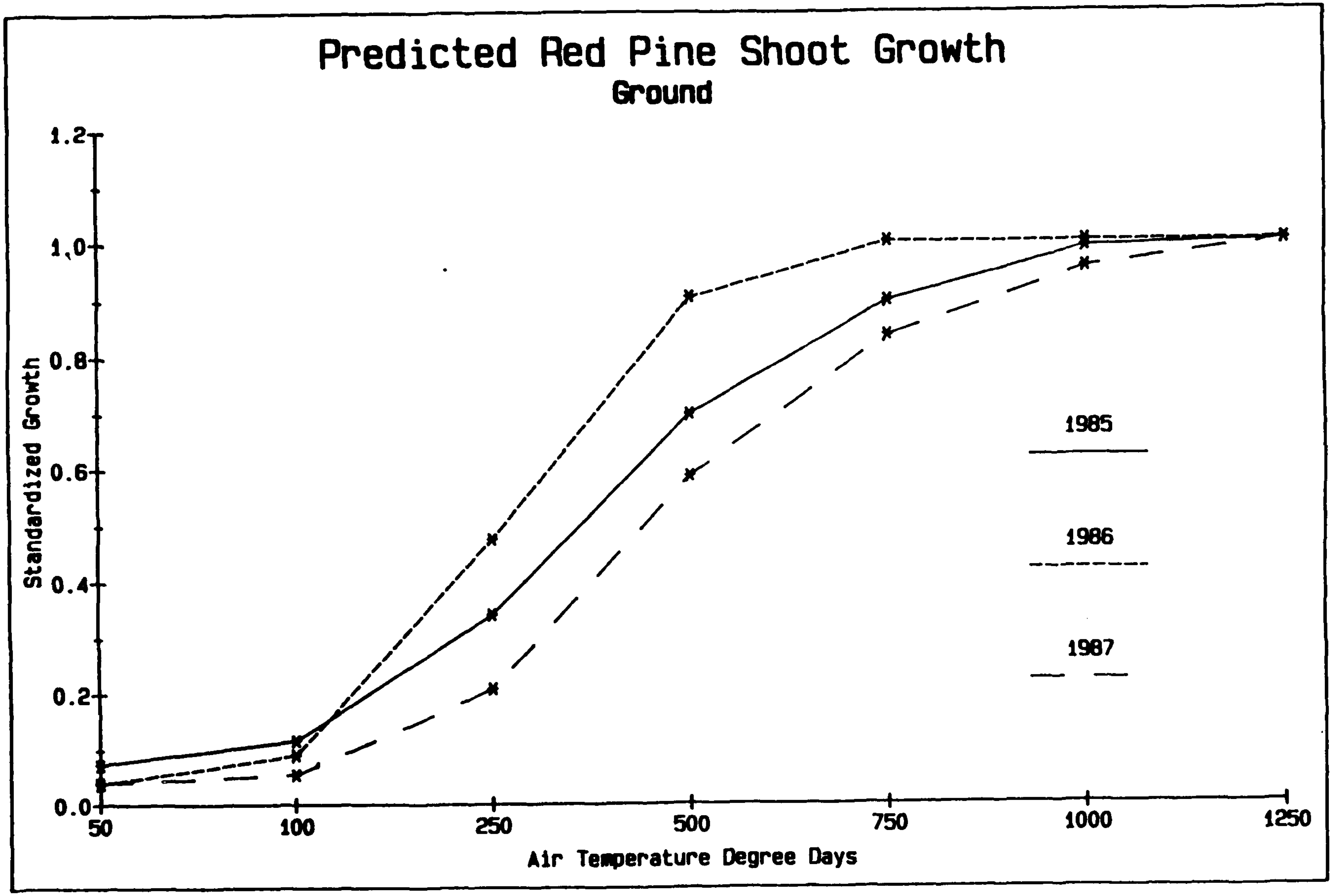
The objective of this work is to determine 1) whether ELF fields have any effect on the nutrition of red pine seedlings and 2) whether red pine foliar nutrient concentrations can be useful in explaining site differences in red pine growth rates.

Red pine foliage was collected from 50 seedlings per site at the time of planting, from 45 seedlings per site in October of 1984 and from 15 seedlings per site in October of the 1985, 1986 and 1987 field seasons. These sample sizes correspond to the number of seedlings used in PMS and mycorrhizae studies with multiple measurements made on each seedling. At each collection period, current year needles were taken from seedlings, dried at 60^{0} C and analyzed for concentrations of N, P, K, Ca and Mg.

Progress

At this time, foliage nutrient analysis has been completed for samples taken at planting through 1986 (Table 2.17). In general, all nutrient concentrations are above

Figure 2.12



Predicted Red Pine Shoot Growth
Ground
Standardized Growth
1.2
1.0
0.8
0.6
0.4
0.2
0.0
50
100
250
500
750
1000
1250
Air Temperature Degree Days
1985
1986
1987

Figure 2.13

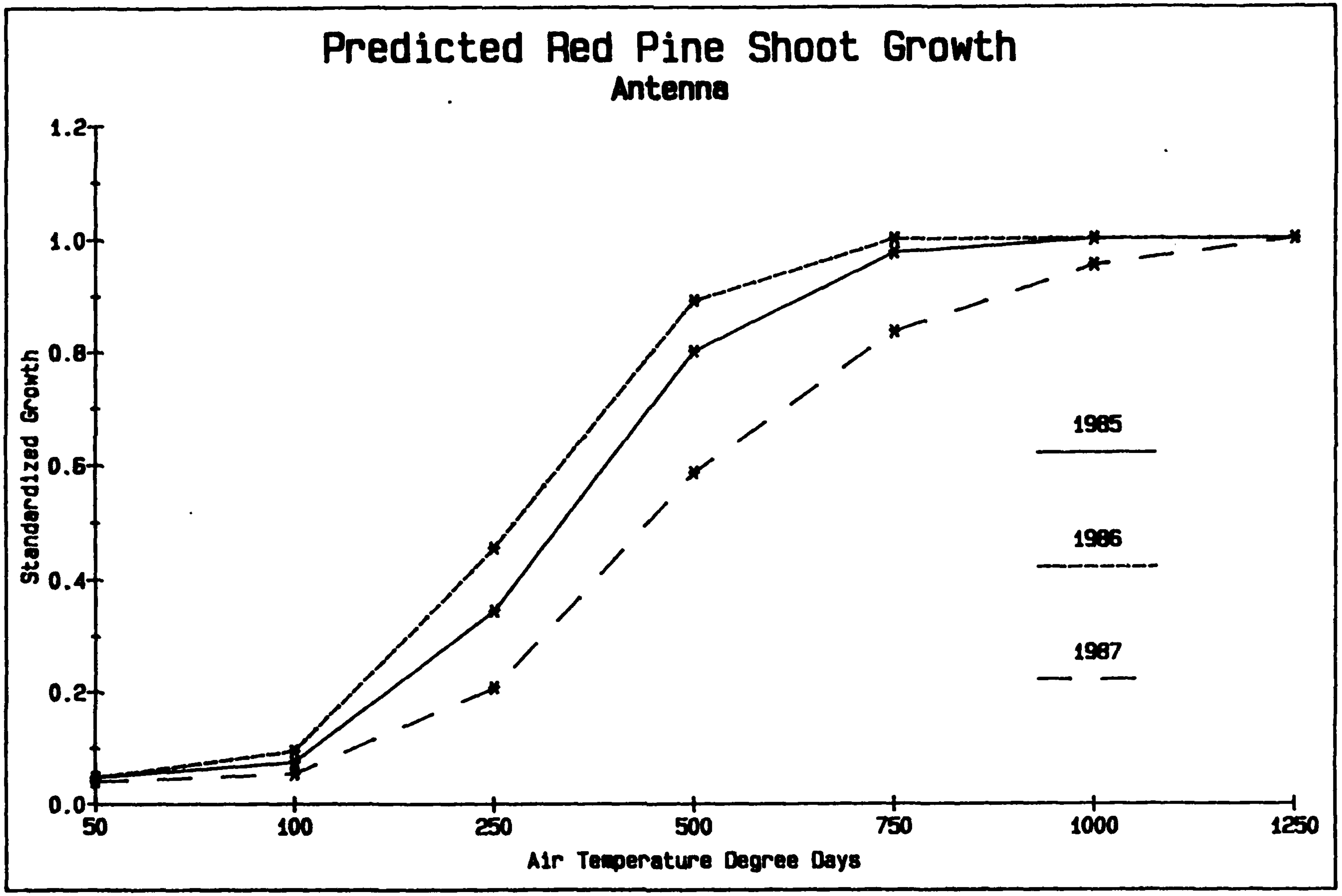
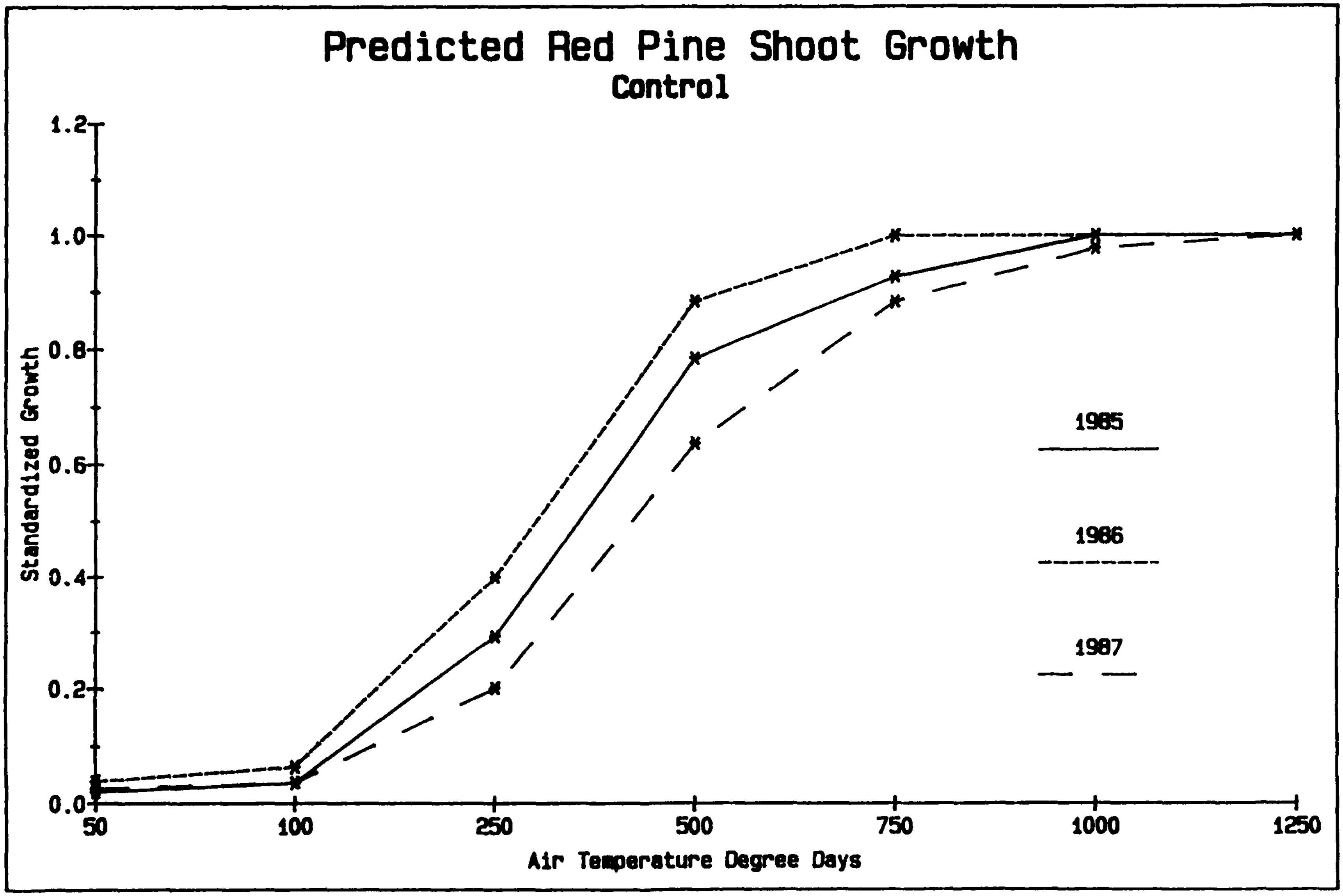
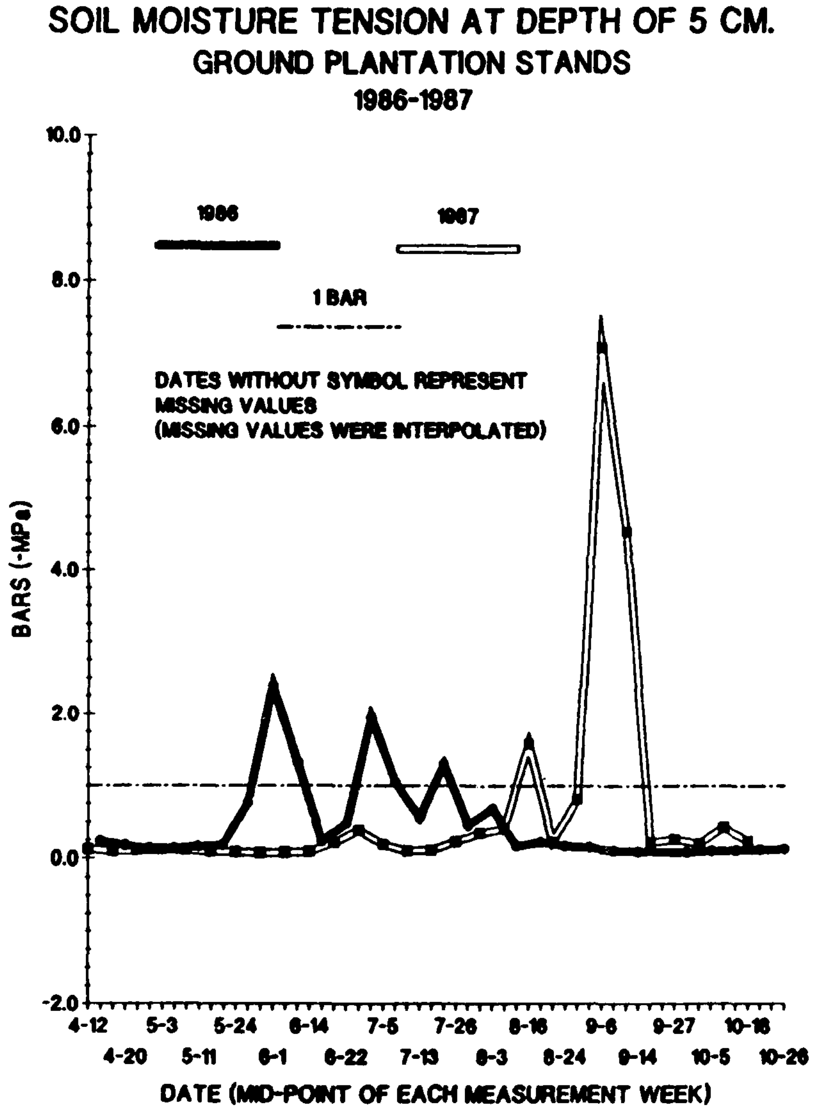

Predicted Red Pine Shoot Growth
Antenna
Standardized Growth
0.0
0.2
0.4
0.6
0.8
1.0
1.2
50
100
250
500
750
1000
1250
Air Temperature Degree Days
1985
1986
1987

Figure 2.14

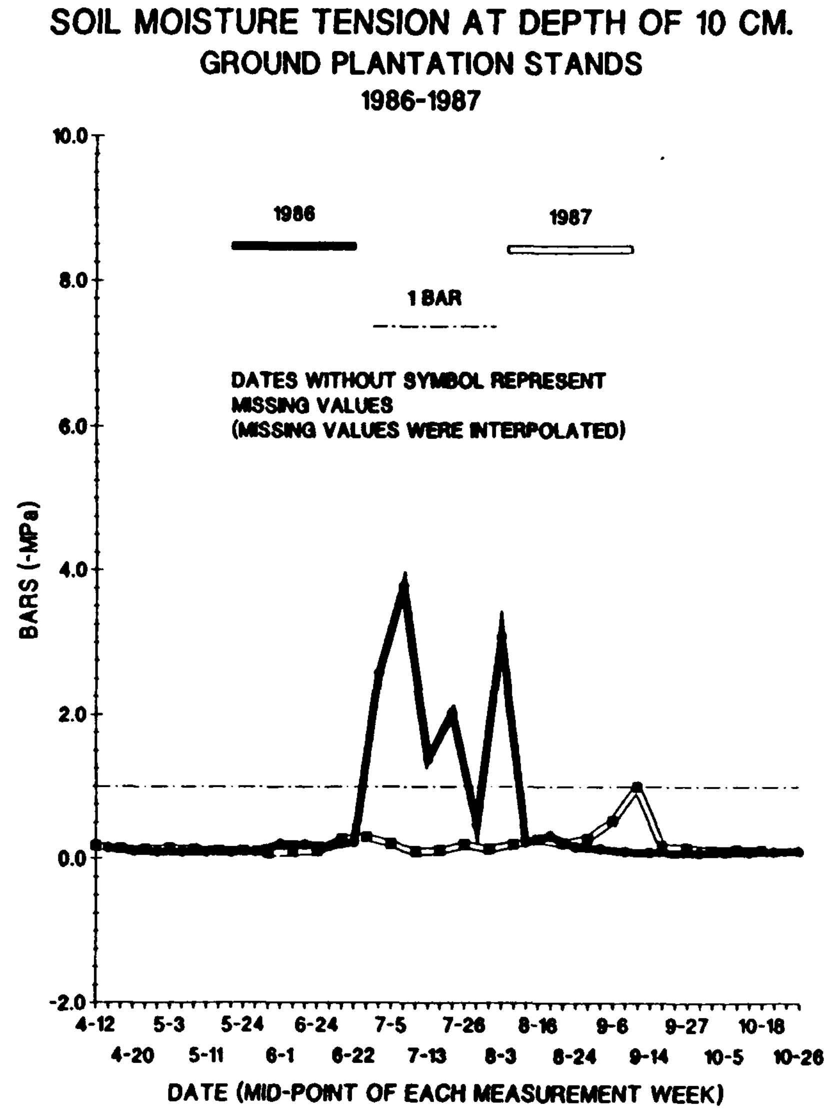


Predicted Red Pine Shoot Growth
Control
Standardized Growth
1.2
1.0
0.8
0.6
0.4
0.2
0.0
50
100
250
500
750
1000
1250
Air Temperature Degree Days
1985
1986
1987

Figure 2.15

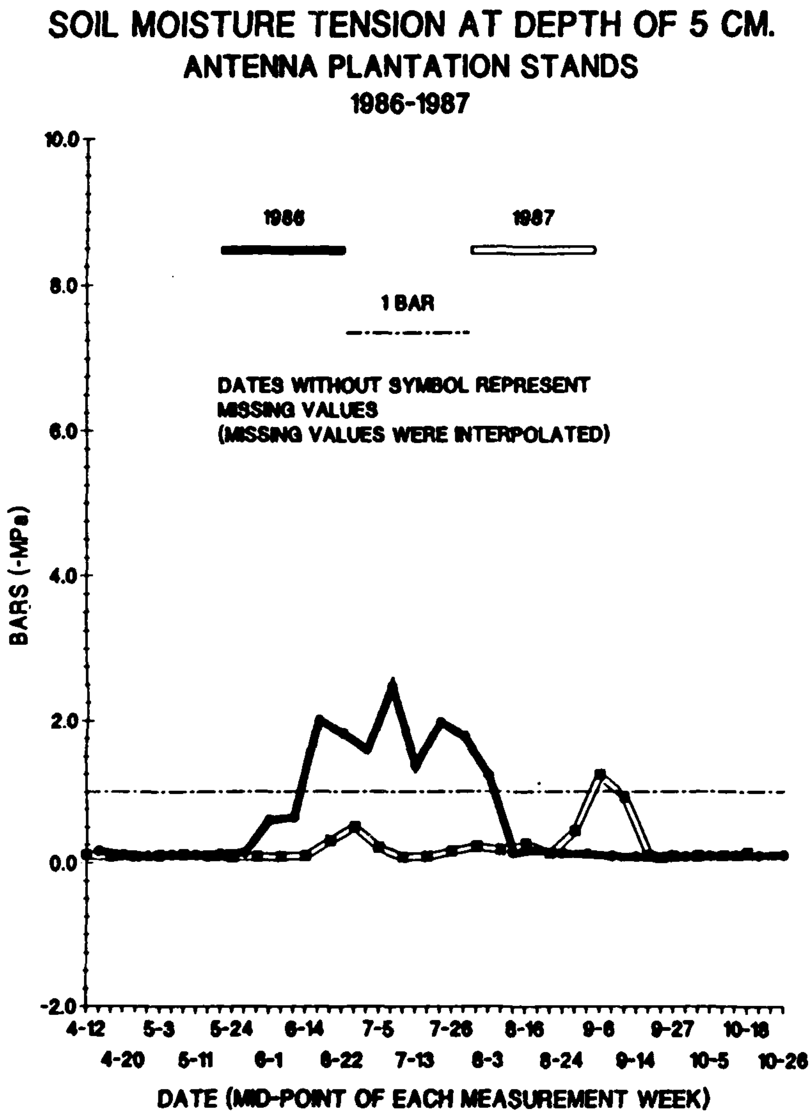


SOIL MOISTURE TENSION AT DEPTH OF 5 CM.
GROUND PLANTATION STANDS
1986-1987
1986
1987
1 BAR
DATES WITHOUT SYMBOL REPRESENT
MISSING VALUES
(MISSING VALUES WERE INTERPOLATED)
BARS (-MPa)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
4-12 4-20 5-3 5-11 5-24 6-1 6-14 6-22 7-5 7-13 7-26 8-3 8-16 8-24 9-6 9-14 9-27 10-5 10-18 10-26
DATE (MID-POINT OF EACH MEASUREMENT WEEK)



SOIL MOISTURE TENSION AT DEPTH OF 10 CM.
GROUND PLANTATION STANDS
1986-1987
1986
1987
1 BAR
DATES WITHOUT SYMBOL REPRESENT
MISSING VALUES
(MISSING VALUES WERE INTERPOLATED)
BARS (-MPa)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
4-12 4-20 5-3 5-11 5-24 6-1 6-24 6-22 7-5 7-13 7-26 8-3 8-16 8-24 9-6 9-14 9-27 10-5 10-18 10-26
DATE (MID-POINT OF EACH MEASUREMENT WEEK)

Figure 2.16


SOIL MOISTURE TENSION AT DEPTH OF 5 CM.
ANTENNA PLANTATION STANDS
1986-1987
1986
1987
1 BAR
DATES WITHOUT SYMBOL REPRESENT
MISSING VALUES
(MISSING VALUES WERE INTERPOLATED)
BARS (-MPa)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
4-12 5-3 5-24 6-14 7-5 7-26 8-16 9-6 9-27 10-18
4-20 5-11 6-1 6-22 7-13 8-3 8-24 9-14 10-5 10-26
DATE (MID-POINT OF EACH MEASUREMENT WEEK)

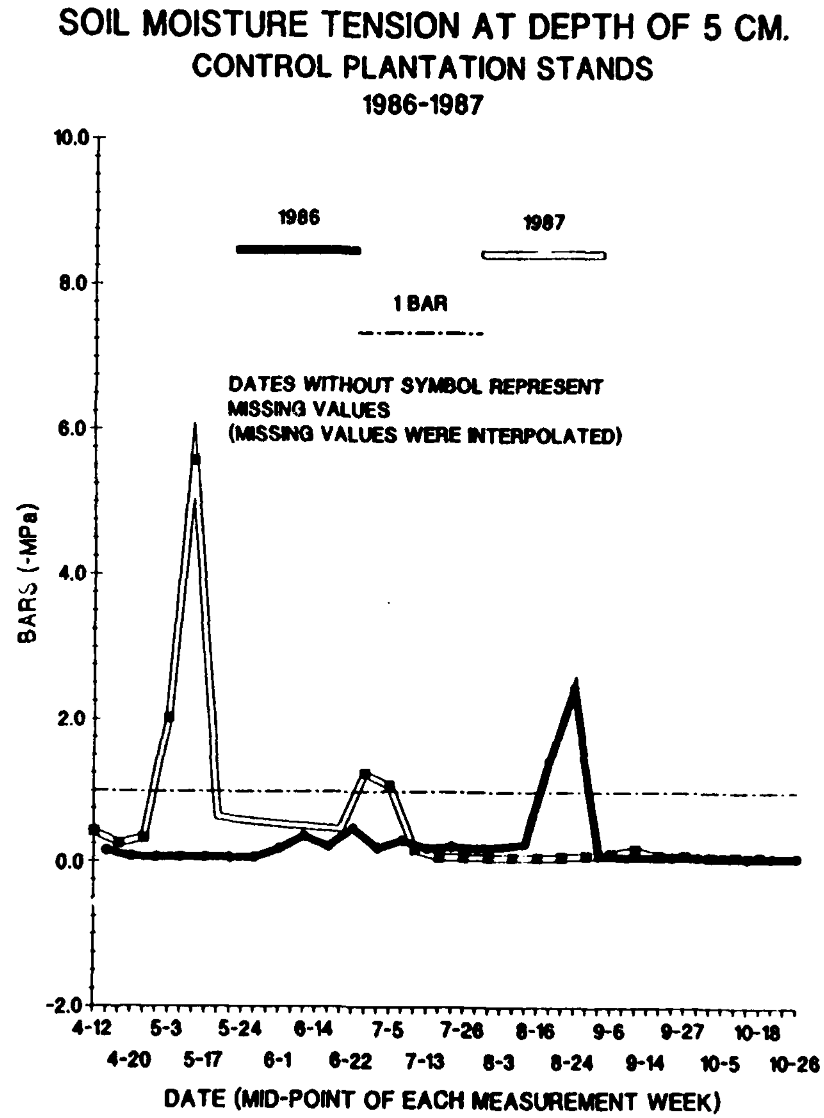
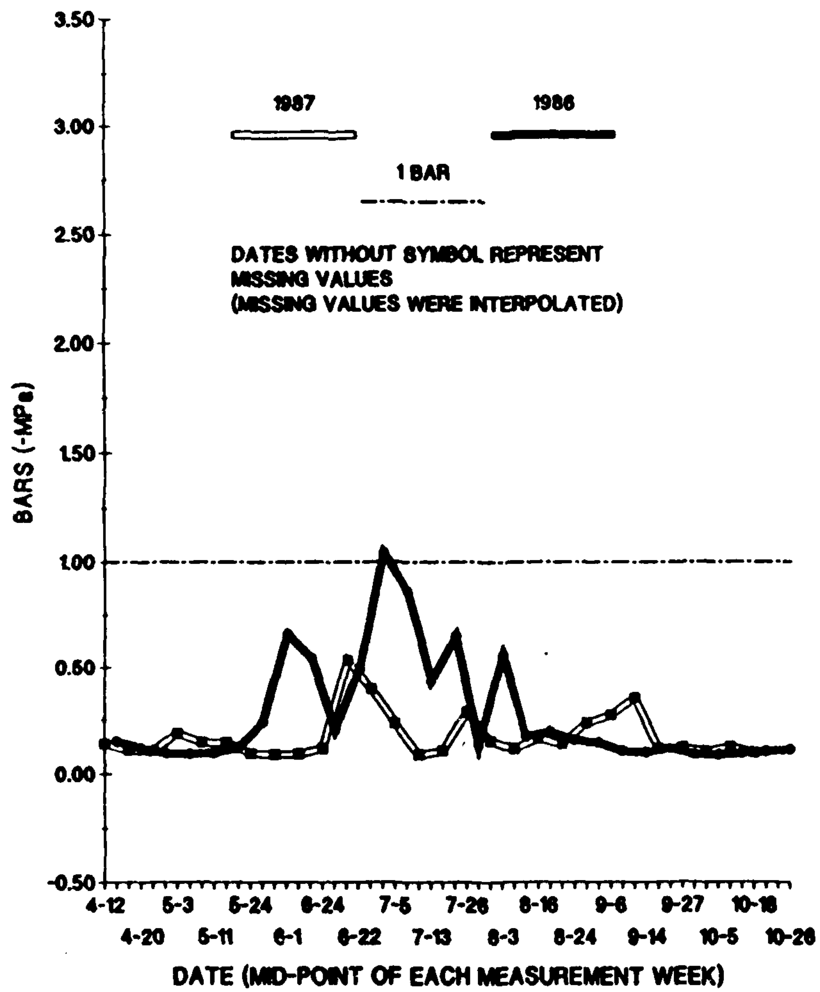

SOIL MOISTURE TENSION AT DEPTH OF 5 CM.
CONTROL PLANTATION STANDS
1986-1987
1986
1987
1 BAR
DATES WITHOUT SYMBOL REPRESENT
MISSING VALUES
(MISSING VALUES WERE INTERPOLATED)
BARS (-MPa)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
4-12 5-3 5-24 6-14 7-5 7-26 8-16 9-6 9-27 10-18
4-20 5-17 6-1 6-22 7-13 8-3 8-24 9-14 10-5 10-26
DATE (MID-POINT OF EACH MEASUREMENT WEEK)

Figure 2.17

SOIL MOISTURE TENSION AT DEPTH OF 10 CM.
ANTENNA PLANTATION STANDS
1986-1987



SOIL MOISTURE TENSION AT DEPTH OF 10 CM.
CONTROL PLANTATION STANDS
1986-1987

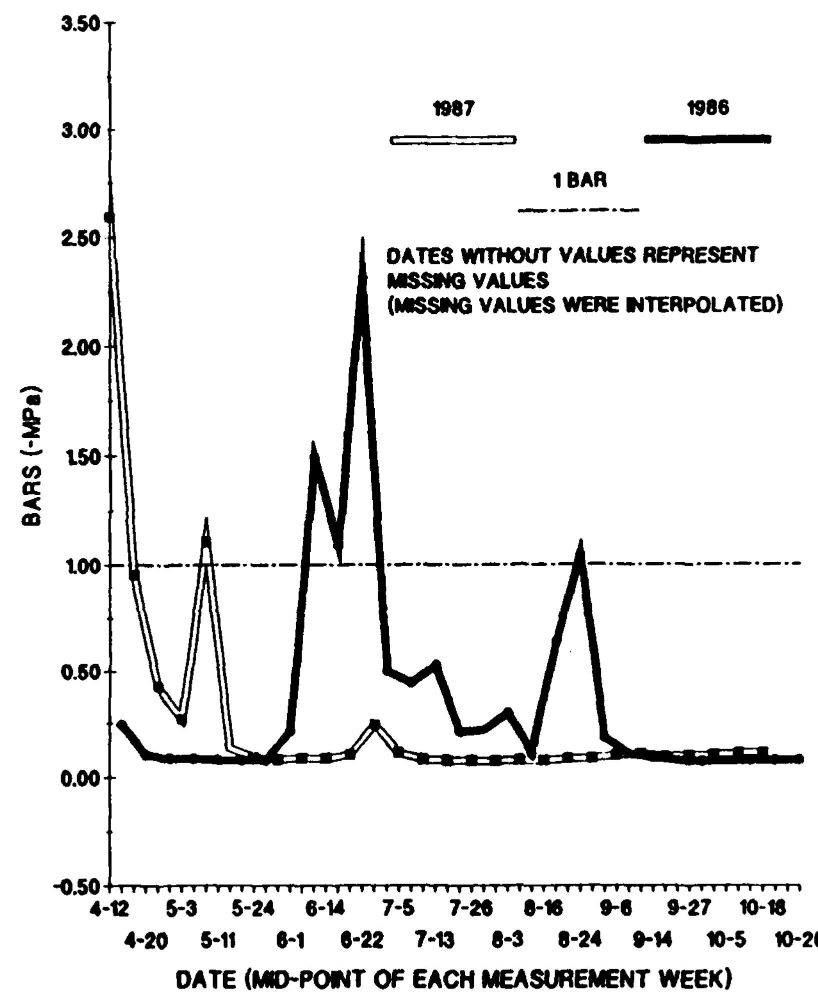


Table 2.17. Foliage nutrient content for red pine seedlings at ELF study sites at the time of planting and three years afterwards.

Site	N	P	K	Ca	Mg
AT PLANTING					
Ground	1.12	0.14	0.40	0.22	0.12
Antenna	1.16	0.14	0.39	0.20	0.12
Control	1.15	0.14	0.39	0.22	0.12
YEAR 1					
Ground	1.42	0.15	0.49	0.30	0.13
Antenna	1.50	0.16	0.50	0.31	0.14
Control	1.33	0.15	0.46	0.30	0.13
YEAR 2					
Ground	1.43	0.16	0.51	0.20	0.09
Antenna	1.09	0.13	0.55	0.18	0.08
Control	1.61	0.18	0.55	0.23	0.10
YEAR 3					
Ground	1.42	0.13	0.47	0.19	0.08
Antenna	1.59	0.14	0.51	0.18	0.08
Control	1.34	0.13	0.49	0.23	0.09

levels reported for adequate growth of red pine. Critical levels have been reported for K (0.35%), Mg (0.05%), and Ca (0.12%), while concentrations of N above 1.0% and P above 0.16% have been found to be adequate for growth in plantations (Stone and Leaf, 1967; Hoyle and Mader, 1964; Alban, 1974). Nutrients are ranked in the order: N > K > Ca > P > Mg for all years sampled.

No attempts have been made to include foliage analyses in red pine growth analyses at this time. Analyses to examine site and year differences have recently been initiated. Analyses without covariates show site differences only for foliar concentrations of K (Table 2.18). Using shoot-root ratio as a covariate, much of the difference between sites was explained, but significant differences remain. There were also strong differences between sample years for all nutrients which can not be explained by covariates at this point. Until these differences can be further examined detection limits will not be calculated.

Analyses in the next year will examine nutrients for possible inclusion in growth modeling efforts. In addition, other covariates such as soil nutrients and ambient climatic factors will be considered in site and year comparisons of seedling foliage requirements. Such an approach has been successfully used by Bicklehaupt et al. (1979). They found degree days and precipitation in the current year and in the period after cessation of height growth in the previous year (due to determinant growth of red pine) to explain yearly fluctuations in foliar nutrient levels.

Red Pine Moisture Stress

Plant moisture stress (PMS) as determined by xylem water tension is a measure of the internal moisture status of plants and can be a useful indication of overall physiological condition. Optimal tree growth is dependant on many factors such as healthy root systems which allow adequate uptake of water and nutrients. Similarly, the aboveground biomass must function properly to translocate water and nutrients from the roots to provide photosynthate for growth. A physiological change that would effect the function of the root system and aboveground biomass may also effect the growth of the plant. Such changes may affect the internal moisture status. Thus, changes in PMS may indicate changes in physiological processes that affect growth.

Plant moisture stress can also be used to help explain growth differences between sites. Site characteristics such as soil physical and chemical properties, microsite, water holding capacity, and climate have an effect on the growth of red pine. Because red pine is not genetically diverse, seedling growth expresses the potential of a site to provide optimal conditions for growth. The quality of the site is thus reflected in the growth of the seedling. If site quality

Table 2.18. Results of red pine foliage covariate analyses.

	P Value				
	CA	MG	K	N	P
Without Covariates					
Site	.095	.052	.017	.305	.342
Date	.000	.000	.000	.000	.000
Date x Site	.004	.138	.052	.002	.015
With Seedling Height					
Site	.171	.297	.033	.147	.258
Date	.000	.000	.000	.000	.004
Date x Site	.009	.200	.059	.006	.021
With Shoot Root Ratio					
Site	.084	.068	.059	.445	.386
Date	.000	.000	.000	.044	.015
Date x Site	.006	.143	.022	.003	.018
With Total Mycorrhizae					
Site	.201	.379	.003	.952	.778
Date	.000	.000	.000	.000	.001
Date x Site	.038	.326	.160	.002	.038
With Mycorrhizal Per Gram of Root Weight					
Site	.364	.544	.017	.985	.957
Date	.000	.000	.000	.000	.000
Date x Site	.044	.371	.430	.004	.024
With Seedling Top Weight					
Site	.242	.062	.027	.879	.517
Date	.000	.000	.000	.000	.000
Site x Date	.009	.165	.057	.005	.013
With Seedling Root Weight					
Site	.306	.297	.029	478	.468
Date	.000	.000	.000	.000	.000
Date x Site	.011	.238	.058	.005	.014

is not optimum, physiological growth processes are also not at an optimium level and this may be reflected in internal moisture status.

Finally, PMS values can be used to indicate moisture stress during periods of drought. Extended drought can reduce water uptake and reduce growth and survival of red pine seedlings. The PMS values may help explain differences in year to year growth that are due to drought conditions. In effect, PMS reflects the integrated effects of physiological processes and environmental conditions on seedling growth as indicated by internal moisture status. Therefore, the overall objective of the red pine moisture stress study is to quantify the PMS/growth relationship prior to and after the activation of the ELF antenna and evaluate the usefulness of PMS as a covariate in the growth analysis of red pine.

Sampling and Data Collection

PMS sampling was conducted in years 1984 - 1987. The red pine seedlings were planted in June 1984 and became established during that growing season. PMS values were much higher in 1984 than for 1985 - 1987 due to planting shock and do not accurately reflect PMS of established seedlings. Furthermore, ambient monitoring data is not available for 1984 for use as covariates. Therefore, 1984 PMS data is not included in this analysis.

Sampling was conducted bi-weekly beginning on May 30 and continuing until September 15 on the ground, antenna, and control sites. Sampling was not conducted after this time due to cold temperatures at the scheduled time of sampling and subsequent frozen xylem water in the seedling; this results in high moisture stress values that are not an accurate reflection of seedling moisture status. In past years, a lateral shoot with 2 years of needles was severed from each seedling and used in PMS determination. However, in 1986 the lateral shoots began to exceed the capacity of the PMS pressure chamber. In an attempt to address this problem, we considered using smaller plant parts (i.e. needles) in PMS determination. Consequently, in August 1986, a support study was conducted to determine whether using various parts of the seedling would result in differing PMS values. It has been reported (Cleary and Zaerr, 1984) that any portion of the plant may be used in PMS measurements. This support study was conducted to determine if PMS differences exist in various plant components. Specifically, we needed to determine whether data based on needles could be compared to past years data based on lateral shoots. Four components of red pine seedlings were tested:

1.) Current year terminal shoot
2.) Lateral shoot with two years growth
3.) Lateral shoot with three years growth
4.) One year old needles

Twenty seedlings were randomly selected at the antenna site and PMS determined for each plant component (Table 2.19). There were no differences in PMS values among seedling components (p=0.05). There was slight variability with PMS of one year old needles the lowest (-.36 Mpa), while lateral shoots with three years growth was the highest (-.44 Mpa). Based on this study one year old needles were chosen for PMS determination in 1987.

On each sampling date, fifteen actively growing seedlings were randomly selected at each site. A one year old needle was cut from each seedling in the pre-dawn hours and immediately placed in a pressure bomb to determine internal water tension. During the daylight hours prior to PMS determination, basal diameter, shoot elongation, total height, and bud formation status were measured. The aboveground portion of the seedling and a portion of the root system were removed from the site the afternoon following PMS determination to obtain aboveground biomass and mycorrhiza counts.

Progress

Plant moisture stress values are lowest early in the growing season and increase to their highest levels in the fall (Table 2.20 and Figure 2.18). Becker et al. 1987) reported that PMS values ranging from -.80 to -1.1 Mpa did not produce measurable reductions in red pine seedling growth. The 1987 field PMS means range from -.15 to -.81 Mpa which are well below the critical levels reported by Becker. Therefore there appear to have been no moisture deficits at any time during the growing season. Similar results were found in 1985 and 1986 (Appendix F).

Significant (p=0.05) differences exist in 1987 between sampling dates and sites but the site by date interaction was not significant. The same relationships were found in 1986. However, when 1985, 1986, and 1987 data were included in the analysis site differences became non-significant but date, year and the site by year interaction were significant. Because PMS is being considered as a possible covariate in the red pine growth analysis we must account for these differences to determine if PMS is independant of ELF fields. This can be accomplished by analysis of covariance using the split plot design. If covariates can explain site and year differences (p=0.05) then we can conclude that PMS is independent of the ELF fields.

Prior to analysis of covariance, correlations were calculated between tree factors, site factors, weekly averages of ambient data and average plot values for PMS. Variables having the highest correlations were considered as covariates in the analysis. Tree measurement variables were not considered as possible covariates because it is uncertain whether these variables are independant of ELF fields. Several transformations of the ambient data were also used in calculating correlations. Variables with the highest

Table 2.19. Mean PMS values (-Mpa) from four components of red pine seedlings. n=20.

Component	PMS
One year old needle	.36[a]
Terminal shoot	.40[a]
Lateral shoot - 2 years growth	.43[a]
Lateral shoot - 3 years growth	.44[a]

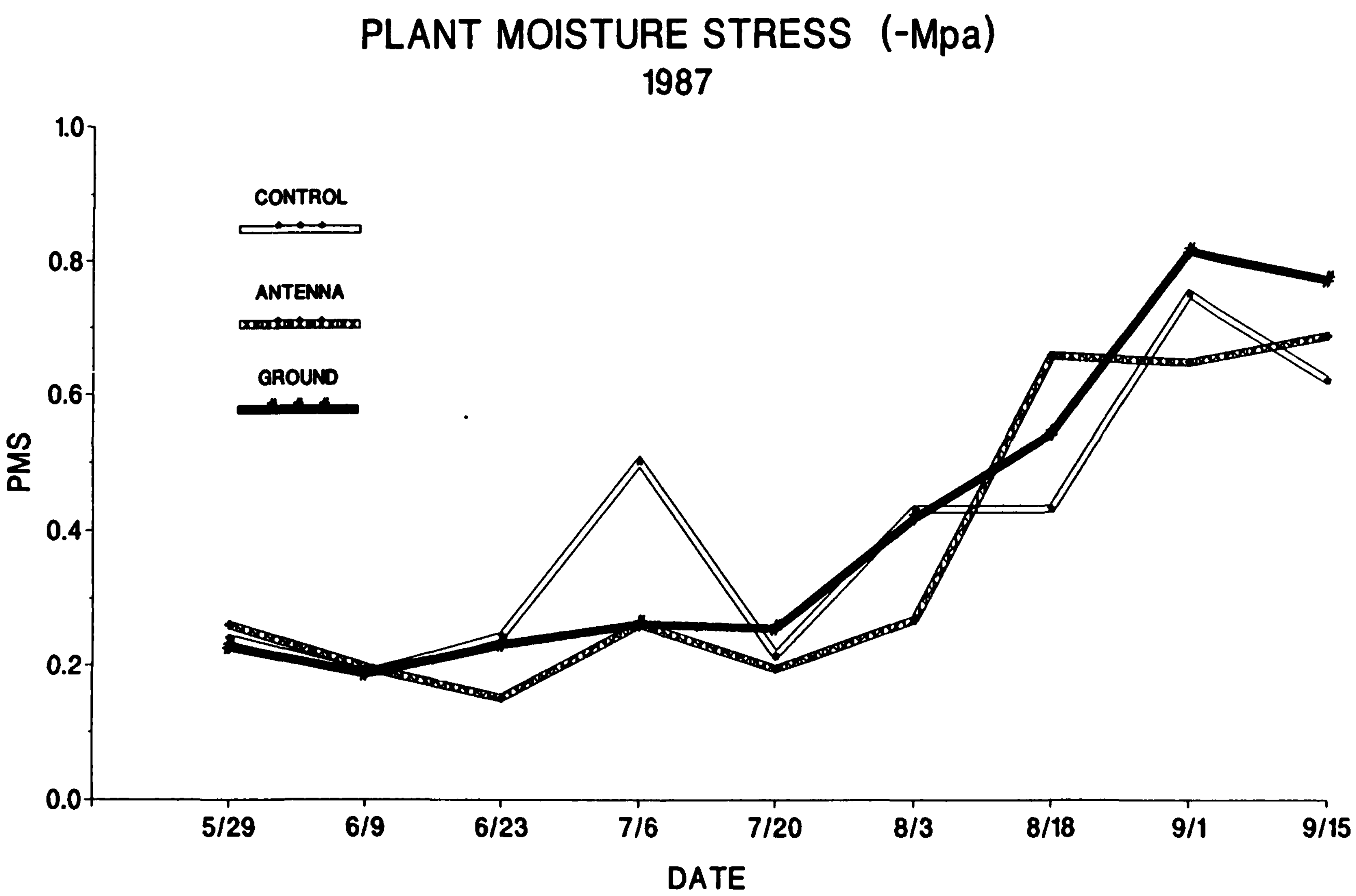
Values denoted by the same letter are not significantly different ($p=.05$).

Table 2.20. Average plant moisture stress values, 1987 (1-Mpa). n=15.

Date	Ground	Antenna	Control	Overall
5/29	.23	.26	.24	.24[ab]
6/9	.19	.20	.19	.19[a]
6/23	.23	.15	.24	.21[ab]
7/6	.26	.26	.50	.34[bc]
7/20	.25	.19	.21	.22[ab]
8/3	.42	.27	.43	.37[c]
8/18	.54	.66	.43	.54[d]
9/1	.81	.65	.75	.74[e]
9/15	.77	.69	.62	.69[e]
Overall	.41[x]	.37[y]	.40[x]	

Values followed by the same letter are not significantly different (p=.05).

Figure 2.18


PLANT MOISTURE STRESS (-Mpa)
1987
CONTROL
ANTENNA
GROUND
PMS
1.0
0.8
0.6
0.4
0.2
0.0
5/29
6/9
6/23
7/6
7/20
8/3
8/18
9/1
9/15
DATE

correlations were selected for inclusion in the analysis of covariance (Table 2.21). Generally correlations were highest (+ or -) for temperature variables. Soil moisture precipitation, and transformed variables were not as well correlated with PMS as the temperature variables.

As mentioned earlier, significant differences exist in PMS for date, year, and the site by year interaction when all three years were included in the analysis. Analysis of covariance using the variables listed in Table 2.21 as covariates did not remove these differences although significance levels increased. In addition, various combinations of these variables did not reduce the differences further. SMAT (weekly soil moisture 10 cm * weekly soil temperature 10 cm) did the best in terms of explaining these differences, but the significance levels remained less than 0.05. A summary of significance levels and detectable differences for PMS using SMAT as a covariate is presented in Table 2.22.

Future efforts will focus on using additional covariates to try to explain remaining differences in PMS. Soil water tension, available soil water, and transformations of selected variables will be used as covariates. In particular, soil water tension will be investigated because it has a direct relationship to PMS in needles of loblolly pine (Kramer 1983). Kramer (1983) further reports that water uptake in white pine was reduced as root temperatures decreased. Although soil temperature variables as covariates did help to explain some of the differences in PMS, additional work will be done with these variables to investigate the relationship between soil water tension, soil temperature, and PMS.

At this point, the analysis of covariance to determine whether PMS is independent of ELF fields is partially completed. Therefore, we cannot conclude whether or not ELF has had a detectable effect on PMS at low level of exposure in 1987.

Red Pine Seedling Mortality - Armillaria Root Disease

Armillaria root disease mortality among the planted red pine seedlings was first noted in 1986, the third year following stand conversion. *Armillaria* root disease is the only fatal infectious disease documented to date in the plantations. We are evaluating epidemiological factors controlling the rate of seedling mortality because 1) additional mortality due to this disease is expected to develop with increasing plantation age, 2) the rate of mortality appears to be increasing (at least at the Control site), and 3) mortality appears to be developing at a greater rate on the Control site than at either of the treatment sites.

The causal agent of this disease is at least one member of the *Armillaria mellea sensu* lato species complex (Wargo and Shaw III 1985). These fungi cause a white rot type of decay in woody debris, stumps and moribund root systems, which are

Table 2.21. Pearson correlation coefficients between PMS and selected ambient variables.

Maximum average daily temperature for the week	-.54**
Average weekly soil temperature 10 cm	-.50**
Average weekly soil temperature 5 cm	-.50**
Average weekly air temperature	-.48**
Minimum average daily temperature for the week	-.43**
Weekly total air temperature degree days	.41**
Weekly soil moisture 10 cm * weekly average air temperature (SMAT)	.50**
Average weekly soil moisture 10 cm	.29**
Average weekly soil moisture 5 cm	.21*
Weekly precipitation	.09

significant at: * p = .01
** p = .001

Table 2.22. Test results of PMS with SMAT as a covariate.

Factor	p-value	Detectable Differences*	% of Mean
Site	.347	.10	20.6
Date	.019	.61	12.5
Date by Site	.085	.11	21.7
Year	.001	.31	6.4
Site by Year	.025	.54	11.1

* - Mpa (p=.05)

colonized by means of airborne spores and/or cord-like rhizomorphs. Rhizomorphs grow through the soil, utilizing energy from the decay of one foodbase to colonize the next. Conifer seedlings may be colonized and killed by *Armillaria* spp., either through infection by rhizomorphs or by seedling root growth into contact with decaying foodbases.

Seedling vulnerability depends upon several site and biological factors. First, distribution of mortality is related to the spacing and size of hardwood stump foodbases (Pronos and Patton 1977). Seedling vulnerability increases with proximity to infested foodbases. Second, rhizomorph growth is most efficient in well-aerated light-textured soils with low rock content (Rishbeth 1978, Singh 1981). Third, seedling vulnerability is increased by the addition of any physiological stress, such as severe drought or competition. Because ELF fields represent a possible additional source of stress, the underlying factors governing *Armillaria* root disease development on the three plantation plots will be evaluated. In this way, any role played by ELF fields in determining rates of root disease mortality can be estimated.

The evaluation of *Armillaria* root disease development in the plantation plots is divided into two areas: 1) identification of the responsible pathogen species occurring at each plantation plot, and 2) evaluation of site factors and ambient conditions contributing to annual levels of disease. The overall null hypothesis tested in this phase of the study is:

> H_0: There is no difference in the rate of development of *Armillaria* root disease on red pine seedlings before and after the ELF antenna becomes operational which can not be explained by factors other than ELF field levels.

Sampling and Data Collection

Armillaria root disease mortality has been monitored closely since it first began to develop during the 1986 field season. The position of seedlings killed by *Armillaria* root disease have been marked in the field with wooden stakes and mapped for permanent reference. As soon as seedlings develop the gray-green foliage color symptomatic of fatal decline, they are pulled up for diagnosis based on the presence of characteristic mycelial fans under the bark at the root collar. Infected seedlings are then returned to the laboratory for cultural isolation of the pathogen onto potato dextrose agar in petri dishes. *Armillaria* isolates are maintained permanently for reference.

Because of the primary importance of stumps and their associated root systems as foodbases for *Armillaria*, it was necessary to quantify the stump populations on the ELF plantations in order to explain the distribution of root disease on red pine seedlings. Each plantation plot was therefore represented as 12 quarter-replicates for purposes of mapping and analysis. Right angle prisms were used to map the

location of each stump or dead seedling on a Cartesian coordinate system.

The genetic unit of study in populations of Armillaria spp. is the clone, the vegetative individual, which grows and extends itself from one foodbase to the next in the form of rhizomorphs. Clones can be distinguished in the laboratory through cultural confrontations on malt extract agar between isolates derived from dead seedlings, decaying stumps, or Armillaria mushrooms. Isolates from the same clone grow together and intermingle freely, whereas isolates representing different clones form lines of demarcation where they grow into contact with one another (Kile 1986, Korhonen 1978, Mallett and Hiratsuka 1986, Siepmann 1985). Armillaria clones may be identified to genetically intersterile species in the laboratory by cultural confrontations on malt extract agar between (diploid) representatives of each clone and single-basidiospore isolates (haploid tester strains) representing different Armillaria spp. (Siepmann 1987). The normally fluffy white tester strains become dark and crusty when confronted with compatible diploid isolates of the same species.

Sorting the Armillaria isolates obtained from 1) dying seedlings and 2) associated decaying foodbases into clones will help to confirm or reject hardwood species foodbase preferences suggested by regression analysis. Identification of clones to species is imperative in light of differences in rate of root disease development among the three plantation plots. Armillaria spp. differ in pathogenicity to conifers and hardwoods (Korhonen 1978, Rishbeth 1985) to such an extent that differences in root disease observed among the plantation plots might be explained if the plantations are dominated by different Armillaria spp. For example, Rishbeth (1985) found that the host ranges of A. mellea isolates were more likely to encompass hardwoods as well as conifers than were the host ranges of A. ostoyae isolates. Though both species are considered to be highly pathogenic toward pines, Rishbeth found that his isolates of A. mellea were slightly more virulent toward Scots pine than were his isolates of A. ostoyae.

Multiple regression analysis is being used to identify factors which help to explain differences in Armillaria root disease mortality among sites and years. Regression models are being derived which relate site and ambient conditions as independent variables to the dependent variable, seedling mortality on the quarter-replicates. The overall significance of each tested model is evaluated using the F test for the associated analysis of variance, and the contributions of individual independent variables in each model are evaluated using the corresponding t statistic. The predictive capability of each model is indicated by its associated $r2$ value. Differences among years will be evaluated by incorporating a set of classification (dummy) variables (Searle, 1971) into the regression model. This produces a model identical in structure to the analysis of covariance

model. The interpretation can be quite different because we are concerned with both the classification and continuous (analogous to covariates) variables, while the classical ANCOVA model uses the covariates only to produce more homogeneous experimental material, thereby to reduce error.

Monitoring Armillaria Root Disease

Table 2.23 presents mortality data for 1986 and 1987 on the 9 plantation plot replicates. Striking differences in mortality among plots and plot replicates are apparent. Statistical analyses to date concerning these differences are described in the next subsection. In general, the rate of mortality increased between 1986 and 1987, especially at the Control site. Although the percentages of planted seedlings killed to date are still small, the plantations are only 4 years old and mortality is expected to continue to increase throughout the duration of these ELF studies.

To date, 142 isolates collected in 1986 have been sorted into 26 clones. These isolates represent 57 dead seedlings and 39, 26, 6, and 14 isolates, respectively, derived from aspen, birch, maple, and oak stumps (Table 2.24). Maps of the spatial distribution of these clones on the plantation plot replicates are presented as Figures 2.20 - 2.28 in Appendix G. Clones appear to be most extensively developed at the Control site, where several clones extend over much of a plantation replicate. We speculate that this may reflect differences in soil texture/rockiness among the sites. Growth of rhizomorphs is probably slower, following a more tortuous path, through the rockier soils at the Ground and Antenna sites. Alternatively, the patterns of distribution 1) of different _Armillaria_ spp. or 2) of birch stumps (see Table 2.28, Model 8, and discussion below) may account for the differences in _Armillaria_ clone size and aggressiveness among the 3 plantations. Further sorting of clones and species will proceed as time permits.

Modelling Armillaria Root Disease Incidence

For convenience, the four quarter-replicates comprising each plantation plot replicate were combined to present the stump/ mortality map data as Figures 2.29 - 2.37 in Appendix H. Numbers of stumps and their basal areas per hectare by species are summarized for each plantation plot replicate in Tables 2.25 - 2.27.

A systematic approach to regression model development has been taken (Table 2.28). Model 1 evaluated the relative importance of numbers of stumps vs basal area as predictors of _Armillaria_ root disease. For this model, the t statistic for numbers of stumps was 1.927 ($P=.063$) and the t statistic for basal area was 0.770 ($P=.447$). Though neither variable was significant in this model, attention was focused on numbers rather than basal area of stumps for subsequent model development. When the total number of stumps was entered as

Table 2.23. Red pine seedling mortality due to Armillaria root disease on each of the nine plantation plot replicates during 1986, 1987, and overall to date, presented both as the number of seedlings killed and as the percentage killed of the original number of seedlings planted.

Replicate	Year	Plantation Plot: Ground		Antenna		Control	
		Number	Percent	Number	Percent	Number	Percent
1	1986	0	0.00	14	0.82	19	0.87
	1987	1	0.04	3	0.18	43	1.98
	Total	1	0.04	17	0.99	62	2.85
2	1986	4	0.16	2	0.12	17	0.78
	1987	4	0.16	5	0.29	36	1.66
	Total	8	0.32	7	0.41	53	2.44
3	1986	5	0.20	11	0.64	4	0.18
	1987	15	0.60	15	0.88	12	0.55
	Total	20	0.80	26	1.52	16	0.73

Table 2.24. Sources of the 142 Armillaria isolates grouped by clone to date.

Clone	Seedling Mortality	Stump Species Aspen	Birch	Maple	Oak	Total
a	0	4	1	2	1	8
b	0	0	1	1	1	3
c	1	1	0	0	0	2
d	0	0	1	1	0	2
e	2	0	0	0	0	2
f	1	1	0	0	0	2
g	4	11	0	0	0	15
h	3	1	1	0	0	5
i	3	1	0	0	0	4
j	2	1	0	0	0	3
k	2	1	0	0	0	3
l	0	2	1	0	0	3
m	2	0	0	0	0	2
n	0	1	1	0	0	2
o	0	1	1	0	0	2
p	11	1	1	0	1	14
q	0	4	0	0	0	4
r	6	2	4	1	1	14
s	2	0	1	0	2	5
t	1	0	1	0	1	3
u	1	1	0	0	0	2
v	0	1	1	0	0	2
w	2	0	0	0	0	2
x	4	3	10	0	3	20
y	8	0	0	0	1	9
z	2	2	1	1	3	9
Total	57	39	26	6	14	142

Table 2.25. Stump numbers and basal area (m^2) per hectare by species for each Antenna plot plantation replicate.

Species	Variable	Plot Replicate 1		2		3	
		Mean[a]	s[b]	Mean	s	Mean	s
Aspen	No. Stumps	485.4	172.3	204.7	79.6	368.4	231.9
	Basal Area	21.2	9.5	12.8	4.4	17.8	10.2
Birch	No. Stumps	169.6	81.9	64.3	35.1	46.8	66.2
	Basal Area	31.4	24.3	9.6	9.7	9.0	12.9
Maple	No. Stumps	391.8	72.4	269.0	112.2	327.5	147.9
	Basal Area	15.5	4.2	21.7	19.3	23.7	10.7
Oak	No. Stumps	29.2	11.7	11.7	13.5	35.1	44.8
	Basal Area	2.5	3.4	1.8	2.6	3.7	6.0
Pine	No. Stumps	11.7	13.5	35.1	30.2	0.0	0.0
	Basal Area	1.7	1.5	5.3	5.2	0.0	0.0
Total	No. Stumps	1087.7	211.4	584.8	195.7	777.8	310.5
	Basal Area	71.1	11.6	68.5	17.9	54.2	7.9

a/Data are summarized over 4 quarter-replicates.

b/Standard deviation.

Table 2.26. Stump numbers and basal area (m^2) per hectare by species for each Ground plot plantation replicate.

Species	Variable	Plot Replicate 1		2		3	
		Mean[a]	s[b]	Mean	s	Mean	s
Aspen	No. Stumps	236.1	126.3	388.2	112.7	408.1	224.4
	Basal Area	11.7	6.3	16.2	3.3	19.1	7.5
Birch	No. Stumps	84.0	75.5	16.0	13.1	42.6	47.7
	Basal Area	4.2	4.4	1.0	1.4	2.3	2.6
Maple	No. Stumps	252.1	108.9	304.1	140.2	218.3	106.3
	Basal Area	17.5	7.1	29.8	7.1	16.2	11.1
Oak	No. Stumps	72.0	27.7	32.0	26.1	54.9	44.4
	Basal Area	21.2	12.8	8.2	6.5	16.7	13.6
Pine	No. Stumps	4.0	8.0	0.0	0.0	3.6	7.9
	Basal Area	0.5	1.1	0.0	0.0	0.1	0.1
Total	No. Stumps	648.3	178.0	740.3	226.9	727.9	357.4
	Basal Area	55.1	19.8	55.4	5.2	54.4	16.2

a/Data are summarized over 4 quarter-replicates.

b/Standard deviation.

Table 2.27. Stump numbers and basal area (m2) per hectare by species for each Control plot plantation replicate.

Species	Variable	Plot Replicate 1 Mean[a]	1 s[b]	2 Mean	2 s	3 Mean	3 s
Aspen	No. Stumps	138.1	102.5	138.1	95.7	161.1	140.5
	Basal Area	6.3	4.5	5.0	2.0	7.6	6.7
Birch	No. Stumps	354.3	112.9	308.3	88.1	308.3	86.8
	Basal Area	24.8	9.9	29.2	18.6	30.1	14.3
Maple	No. Stumps	193.3	53.1	225.5	37.9	202.5	83.7
	Basal Area	7.1	4.6	5.8	2.3	5.6	2.5
Oak	No. Stumps	220.9	58.2	382.0	201.9	266.9	74.4
	Basal Area	20.4	8.5	30.3	11.5	20.3	7.1
Pine	No. Stumps	4.6	9.2	0.0	0.0	0.0	0.0
	Basal Area	0.8	1.6	0.0	0.0	0.0	0.0
Total	No. Stumps	911.2	207.4	1053.8	123.4	938.8	123.0
	Basal Area	59.4	9.6	70.2	10.0	63.6	15.0

a/Data are summarized over 4 quarter-replicates.

b/Standard deviation.

Table 2.28. **Characteristics of regression models tested for explanation of *Armillaria* root disease mortality distribution pattern on all three plantation plots (based on 36 quarter-replicate records).**

Model Number	Equation[a]	R^2	F^b	P^c
1	Y_i = -55.096 + 0.124 TOTNO + 0.951 TOTBA	.161	3.167	.055
2	Y_i = -12.314 + 0.143 TOTNO	.146	5.810	.021
3	Y_i = 33.272 + 0.187 TOTNOD	.184	7.644	.009
4	Y_i = 9.358 + 0.170 TOTNOD + 1.290 TOTBAD	.220	4.653	.017
5	Y_i = 5.818 + 0.015 NOA + 0.293 NOB + 0.156 NOM + 0.105 NOO - .453 NOP	.279	2.318	.068
6	Y_i = 55.213 + 0.331 NOB	.236	10.486	.003
7	Y_i = 52.889 + 1.443 BAB + 0.200 NOB	.260	5.800	.007
8	Y_i = 31.474 + 0.243 NOB + 0.095 TOTNOD	.267	6.006	.006
9	Y_i = 88.224 + 0.0004 NODA + 0.316 NODB - 1.808 NODM - 0.242 NODP	.196	1.460	.232
10	Y_i = 70.387 + 0.391 NODB	.146	5.806	.022
11	Y_i = 61.671 + 0.381 NOLB + 0.273 NODB	.241	5.249	.010

a/ Y_i = number of seedlings killed per hectare (ha)
TOTNO = total number of stumps per ha
TOTBA = total basal area of stumps per ha
TOTNOD = total number of non-sprouting (dead) stumps per ha
TOTBAD = total basal area non-sprouting stumps per ha
BAB = total basal area (m^2/ha) of birch stumps
NOA, NOB, NOM, NOO and NOP = total numbers of aspen, birch, maple, oak and pine stumps per ha, respectively
NODA, NODB, NODM, and NODP = number of non-sprouting stumps per ha of aspen, birch, maple and pine
NOLB = number of sprouting (live) birch stumps per ha

b/ F statistic for the overall model

c/ Level of significance attained by the F statistic for the overall model

the sole independent variable (Model 2), the model was significant (P=.021). Replacing total stump numbers with total numbers of non-sprouting stumps (presumed dead) further improved model significance (P=.009). Including the basal area as well as the number of non-sprouting stumps (Model 4) reduced overall model significance (F, P=.017). In this case, the t statistic for basal area was 1.241 (P=.223) and the t statistic for stump numbers was 2.490 (P=.018).

Further model development focused on differences in mortality attributable to foodbase suitability among stump species. Aspen, birch, maple, oak and pine stumps occur in various mixtures on the 36 quarter-replicates. On the basis of total stump numbers by species (Model 5), only birch stump distribution contributed significantly to explanation of root disease incidence (t=2.127, P=.042). Entering total number of birch stumps as the sole dependent variable (Model 6) greatly improved model significance (P=.003). Including both basal area and number of birch stumps (Model 7) decreased the significance of both the overall model (P=.007) and the variables involved. The t statistics for basal area and stump numbers in Model 7 were 1.040 (P=.306) and 1.227 (P=.228), respectively. When both the total number of birch stumps and the total number of non-sprouting stumps were entered (Model 8), the overall model was highly significant (P=.006), but neither variable dominated. The t statistics for birch stump numbers and total numbers of non-sprouting stumps were 1.936 (P=.062) and 1.184 (P=.245), respectively. When only the numbers of non-sprouting stumps of each species were entered, neither the overall model nor any of the species were significant (Model 9). Including only the number of non-sprouting birch stumps (Model 10) provided a reasonably significant model. Finally, including both the numbers of sprouting and non-sprouting birch stumps (Model 11) improved significance slightly, but only the number of sprouting birch stumps achieved a significant t statistic (t=2.038, P=.050).

At this time, Models 6 and 8 are most informative. To date, birch stump distribution is the most useful single variable for predicting mortality level.

Additional regression analysis will evaluate the relationship between seedling mortality and certain soil physical properties determined for each plantation plot replicate. Three variables, 1) percent rock content by volume, 2) bulk density of soil fraction <2 mm, and 3) percent soil (<2 mm) by volume have been measured at 0-10 cm, 10-30 cm, and 30-50 cm, and will be used.

Element 3: PHENOPHASE DESCRIPTION AND DOCUMENTATION

The herbaceous layer of a northern hardwood ecosystem is one of the most ecologically important components of these forests. Characteristics of these plants provide information on the ecosystem's response to many factors. Phenological events, such as stem elongation, bud break, leaf expansion, flowering, fruiting and leaf senescense for an individual species indicate the plant's response to climatic and edaphic factors. Morphological characteristics, such as leaf area, stem length, number of buds, number of leaves, number of flowers, and number of fruit also indicate the plant's response to climatic and edaphic factors. A plant's phenological and morphological characteristics can provide information on the overall vigor of that plant to withstand major perturbations. It is important, therefore, to monitor the phenological events and morphological characteristics of herbaceous species when evaluating the response of an ecosystem to ELF fields.

Starflower, Trientalis borealis Raf., is an important herbaceous species on the control and ELF antenna sites (see Element 4, Table 4.1). Because phenophases of starflower have been well documented in northern Wisconsin by Anderson and Loucks (1973), it's response to ELF fields can be documented and evaluated with some reliability and comparability.

The objectives of this element are to: 1) describe and document specific phenological events and morphological characteristics of Trientalis borealis prior to and during operational use of the ELF antenna and 2) use these data to test hypotheses of possible changes in physiological and phenological processes due to ELF fields.

The main null hypothesis to be tested each year is:

H_O: There is no difference in the onset of flowering and the timing of leaf expansion of Trientalis borealis between the antenna and control sites within a year.

The hypothesis to be tested over all years is:

H_O: There is no difference in the onset of flowering and the timing of leaf expansion of Trientalis borealis before and after the ELF antenna becomes operational.

Morphological characteristics (number of buds, number of flowers, number of fruit, number of leaves, and maximum leaf area) will also be analyzed within the context of these hypotheses. Ambient characteristics within each year will be tested to determine if they explain significant differences among years and sites for the phenological and morphological characteristics.

Sampling and Data Collection

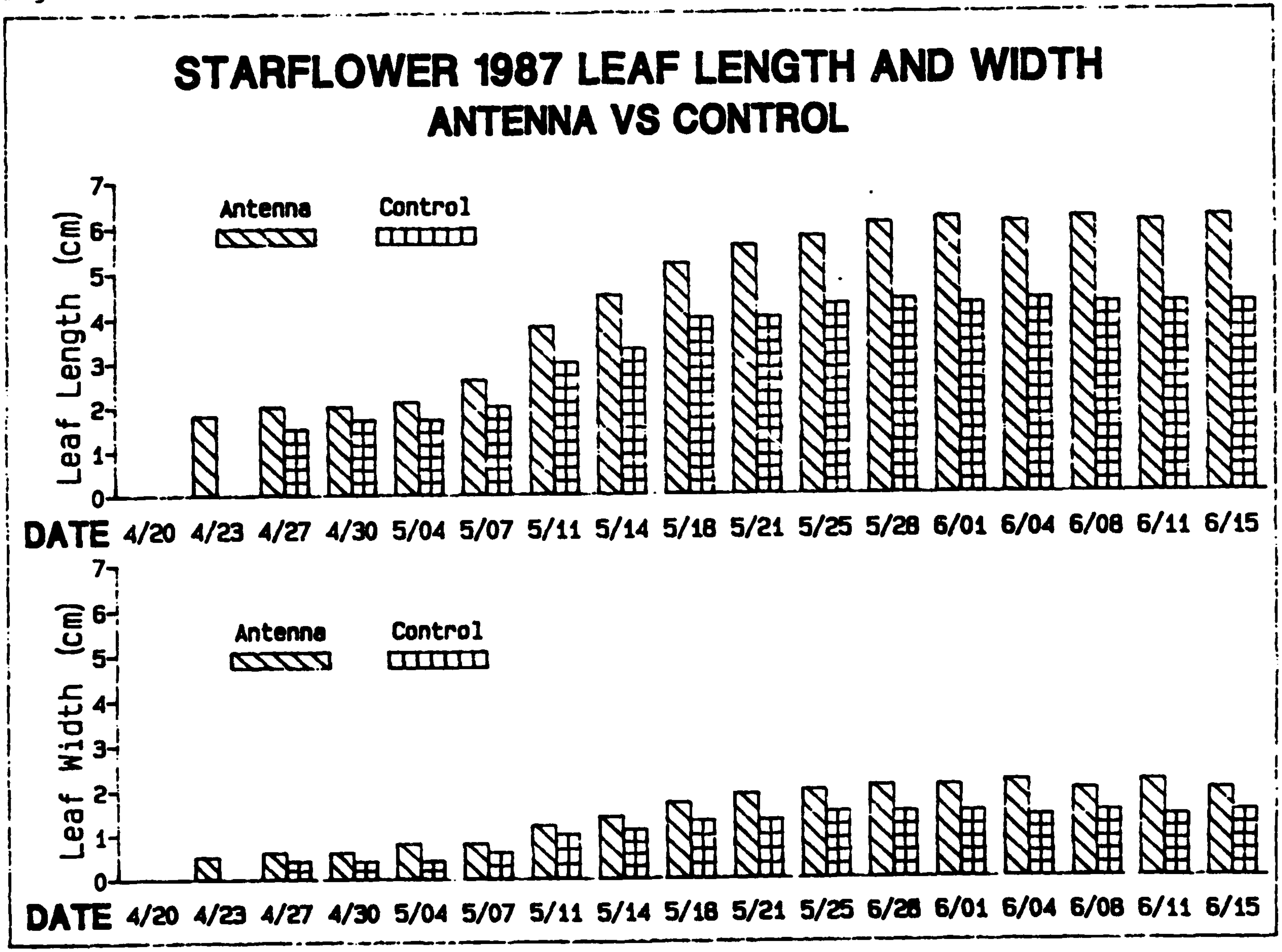
During the 1987 field season, data were collected at the antenna and control sites between April 20 and August 28. Each site was sampled twice a week from April 20 until June 15 to delineate flowering periods and leaf expansion with greater precision. Thereafter, each site was sampled one a week until August 28. Parameters measured per plant for each observation period included stem length, length and width of largest leaf, number of leaves, number of buds, number of flowers, number of fruit, number of yellow leaves and number of brown leaves. To ensure an adequate representation of starflower phenophases, a minimum sample size of 200 individual plants per site was maintained for each observation period during leaf expansion, bud formation, and flowering. To achieve this goal, a single transect line was run and subsequently divided into permanent 1 m^2 subplots. Individual plants within each subplot were then numbered and tagged until a normal distribution of mean stem length was attained. Stem length was used as the response for this determination because it is an indicator of a herbaceous plant's potential sexual productivity. A normal distribution of stem length also insures an adequate representation of the population for analysis of variance techniques. The number of meter square subplots required to obtain a minimum sample size of 200 plants varied between the antenna and control site and among weeks sampled. To reduce bias in choosing the 200th individual, all individual plants were tagged and measured in the subplot where the 200th plant occurred, hence sample size was unequal across sampling days. This sampling method was maintained for each individual plant until tagged individuals began to die or were eaten. Thereafter, observations were taken only on the remaining tagged individuals. Maximum leaf area was estimated for each plant by 1) taking the largest leaves on 15 randomly sampled plants off the herbaceous reserves at each observation period in 1986 and 1987, 2) measuring leaf length, leaf width and leaf area, and 3) developing regression equations for leaf area (dependent variable) using leaf length and width as independent variables.

Progress

Phenological characteristics

Leaf expansion on the antenna site began one week before leaf expansion on the control site. Expansion on the antenna site began sometime between April 20 and April 23, while expansion on the control site began between April 23 and April 27 (Figure 3.1). These differences between sites are probably due to the faster increase in soil temperature in the spring due to low soil moisture contents on the antenna site in comparison to the significantly higher soil moisture contents

Figure 3.1


STARFLOWER 1987 LEAF LENGTH AND WIDTH
ANTENNA VS CONTROL
Leaf Length (cm)
Antenna
Control
DATE 4/20 4/23 4/27 4/30 5/04 5/07 5/11 5/14 5/18 5/21 5/25 5/28 6/01 6/04 6/08 6/11 6/15
Leaf Width (cm)
Antenna
Control
DATE 4/20 4/23 4/27 4/30 5/04 5/07 5/11 5/14 5/18 5/21 5/25 6/28 6/01 6/04 6/08 6/11 6/15

on the control site (see Element 1,Table 1.12). Stem expansion began before April 20 on both sites (Figure 3.2). Bud formation began between April 20 and April 23 on both the antenna and control sites (Figure 3.3). Flowering on the antenna site began one week earlier (May 4 to May 7) than on the control site (May 11 to May 14) (Figure 3.4). Fruiting began one week earlier on the control site compared with the antenna site (May 18 versus May 25 (Figures 3.5 and 3.6)). Leaf senescence (yellowing leaves) and brown leaves, however, began between 3 days and one week earlier on the antenna site (May 25 and May 28, respectively) versus on the control site (June 1 and June 1, respectively) (Figures 3.7, 3.8, 3.9, 3.10). Similar relationships occurred in the 1986 and 1985 growing seasons indicating that the small ELF fields that were present during the 1987 growing season had no distinguishable effect on the timing of starflower's phenological events (Appendix I).

Analysis of covariance (ANCOVA) was used to determine if climate variables could be used to explain differences in stem expansion (cm/time period), leaf expansion (cm/time period), and leaf area expansion (cm^2/time period) between sites (antenna vs control), years, and site by years (Table 3.1).

Table 3.1. Analysis of Covariance table for stem expansion, leaf expansion, and leaf area expansion.

Source of Variation	df	SS	MS	F
Year	2	SS_y	MS_y	MS_y/MS_{e1}
Covariates	#	SS_{cy}	MS_c	MS_c/MS_{e1}
Error 1 (W/Y)	15-#	SS_{e1}	MS_{e1}	
Site	1	SS_s	MS_s	MS_s/MS_{e2}
Site by Year	2	SS_{sy}	MS_{sy}	MS_{sy}/MS_{e2}
Covariates	#	SS_{cs}	MS_{cs}	MS_{cs}/Ms_{e2}
Error 3 (SW/Y)	15-#	SS_{e2}	MS_{e2}	

In the initial analysis of variance without covariates, stem expansion on the antenna site was significantly different from the control site ($p<0.01$). Leaf expansion and leaf area expansion on the antenna site were also determined to be significantly different from the control site ($p=0.03$). To determine which covariates to add in the analysis, correlation values between the response variables and the climate variables. All climate variables, except solar radiation, were significantly correlated ($p<0.01$) to all three response variables. Soil temperature degree days running totals at 5 cm and at 10 cm were the most highly correlated with stem expansion ($r=0.26,0.25$, respectively), leaf expansion ($r=0.58,0.58$, respectively) and leaf area ($r=0.54,0.55$, respectively). However, scatterplots of soil temperature

Figure 3.2

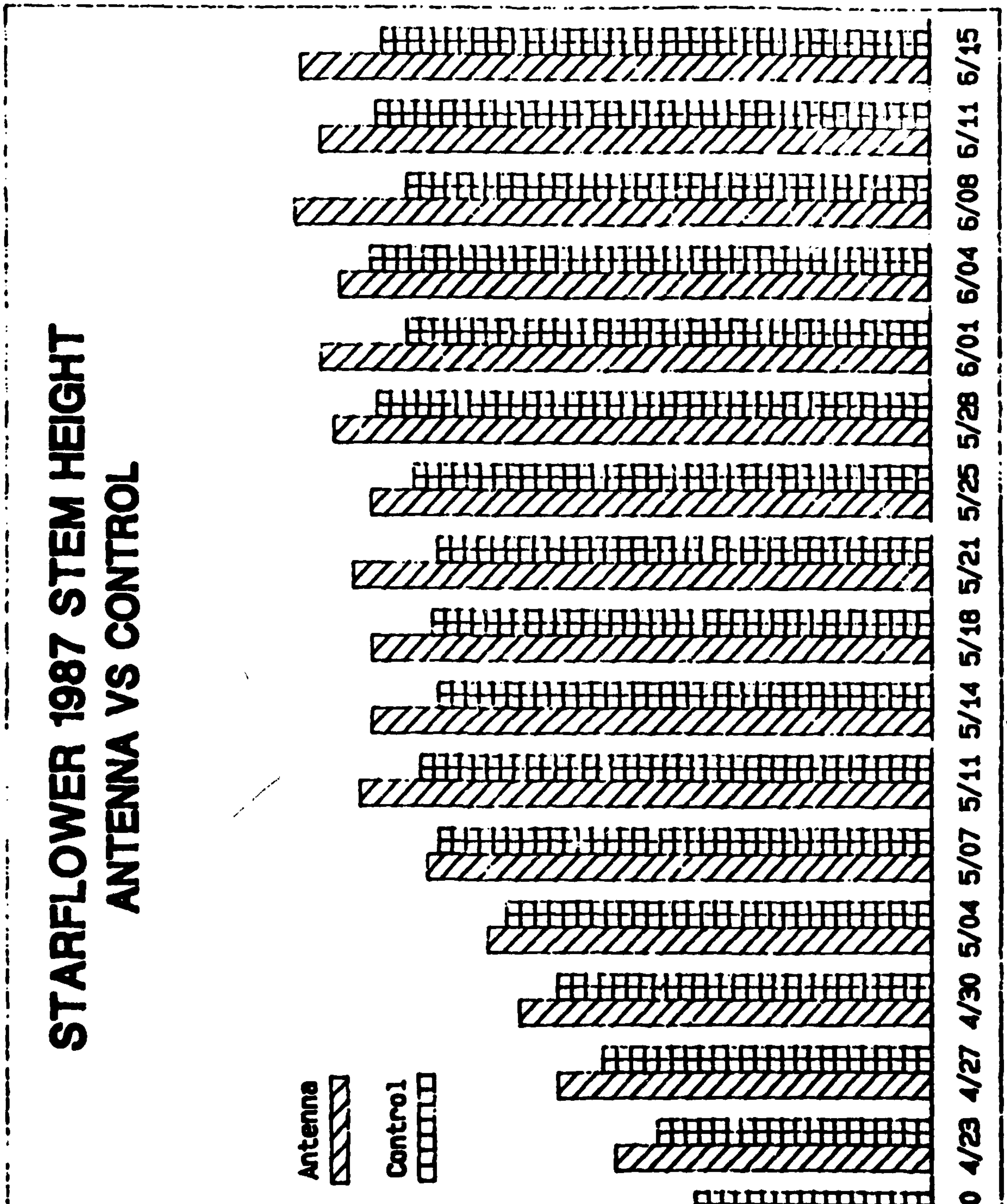

STARFLOWER 1987 STEM HEIGHT
ANTENNA VS CONTROL
Antenna
Control
STEM LENGTH (cm)
0
2
4
6
8
10
12
DATE
4/20
4/23
4/27
4/30
5/04
5/07
5/11
5/14
5/18
5/21
5/25
5/28
6/01
6/04
6/08
6/11
6/15

Figure 3.3

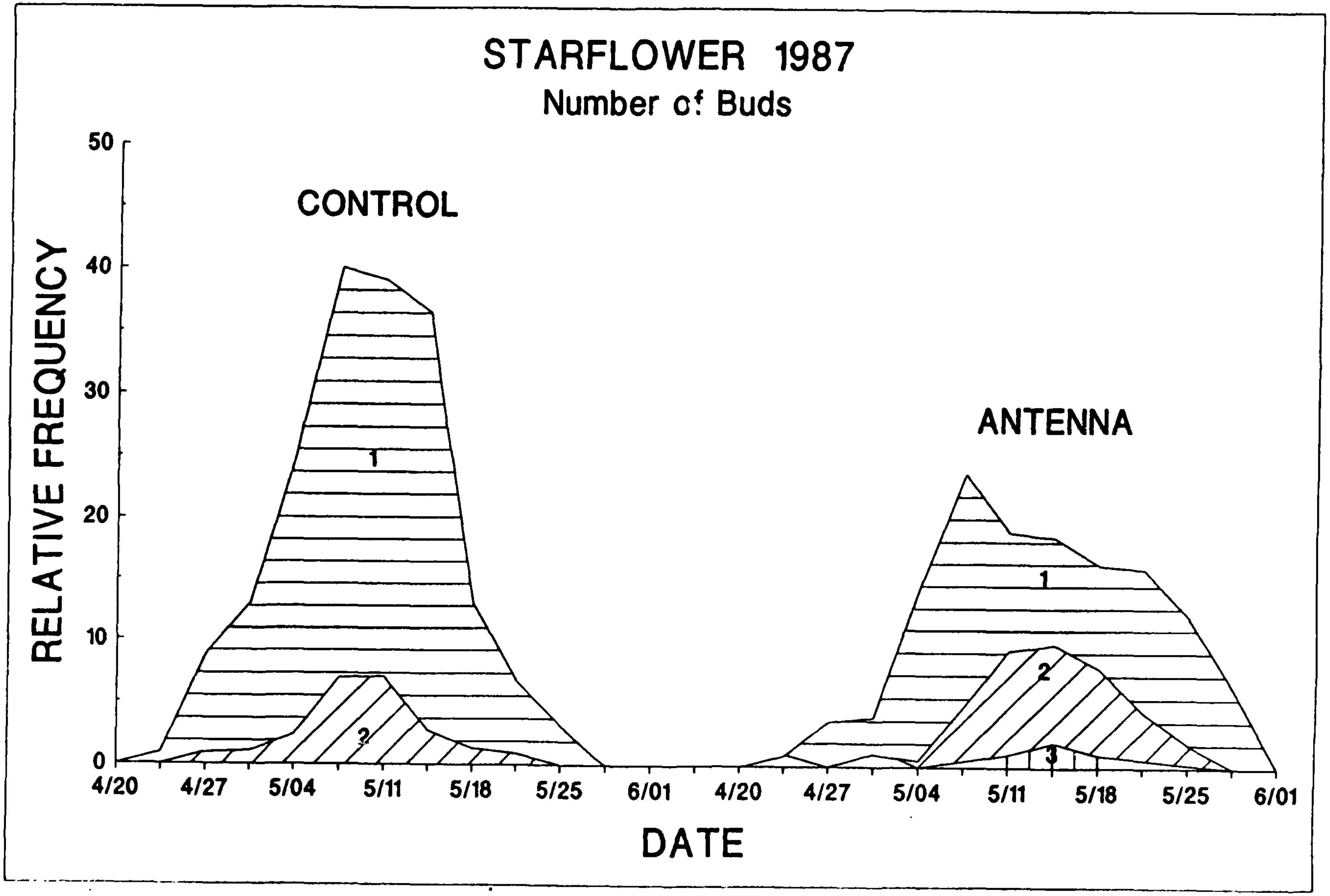
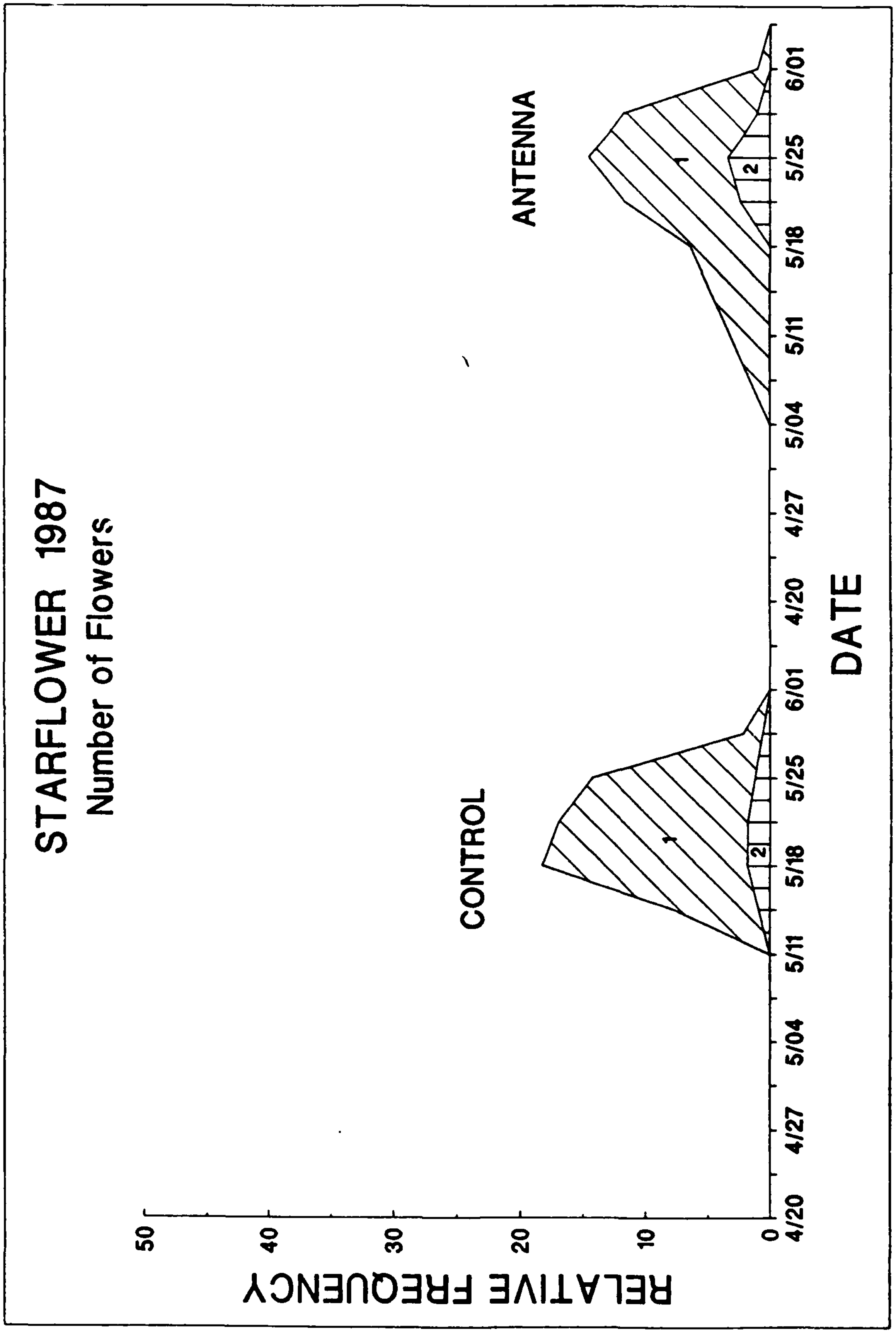

STARFLOWER 1987
Number of Buds
CONTROL
ANTENNA
1
2
1
2
3
50
40
30
20
10
0
4/20
4/27
5/04
5/11
5/18
5/25
6/01
4/20
4/27
5/04
5/11
5/18
5/25
6/01
RELATIVE FREQUENCY
DATE

Figure 3.4



STARFLOWER 1987
Number of Flowers
CONTROL
ANTENNA
1
2
RELATIVE FREQUENCY
0
10
20
30
40
50
DATE
4/20
4/27
5/04
5/11
5/18
5/25
6/01

Figure 3.5

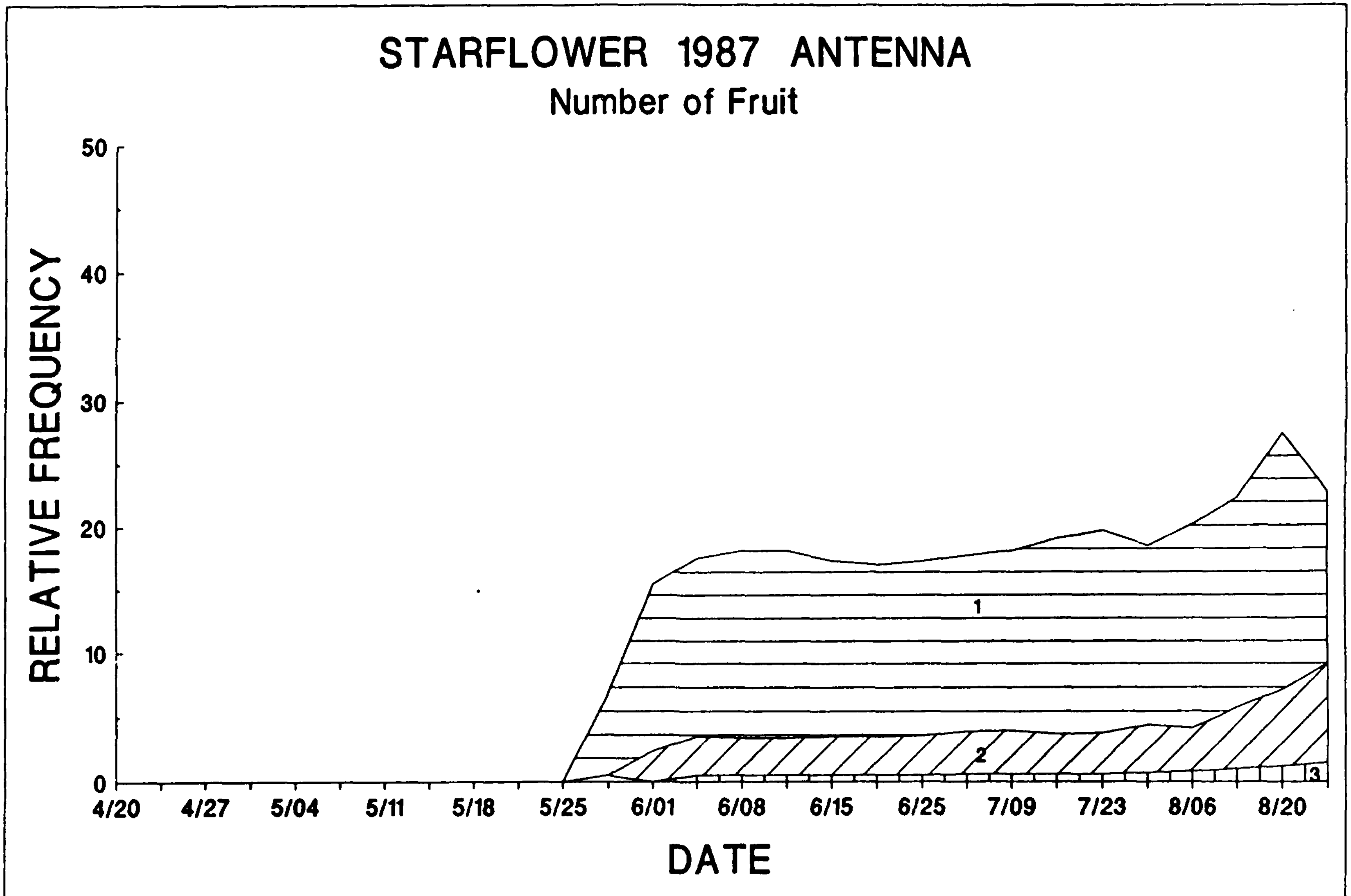

STARFLOWER 1987 ANTENNA
Number of Fruit
RELATIVE FREQUENCY
0
10
20
30
40
50
4/20
4/27
5/04
5/11
5/18
5/25
6/01
6/08
6/15
6/25
7/09
7/23
8/06
8/20
DATE
1
2
3

Figure 3.6

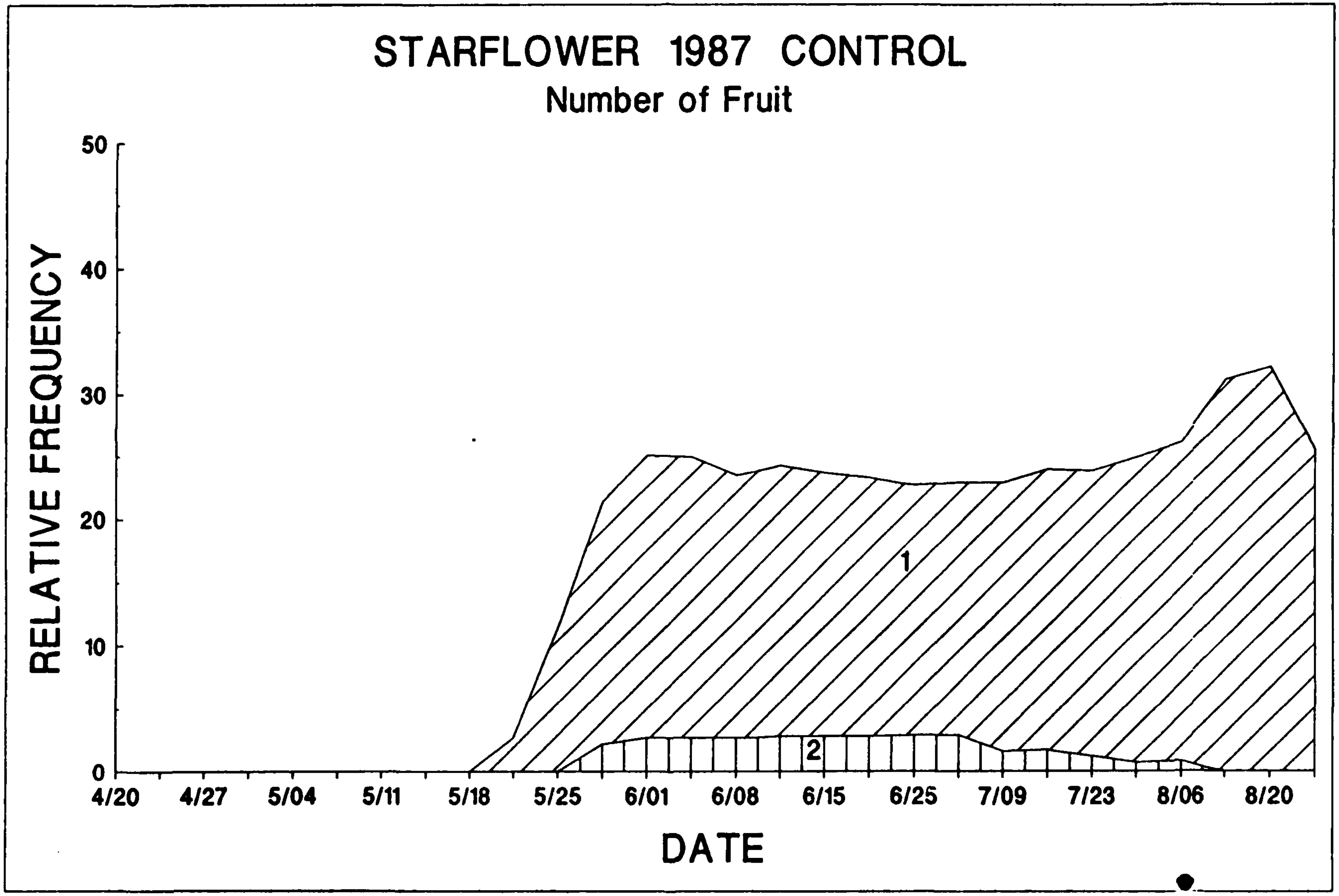
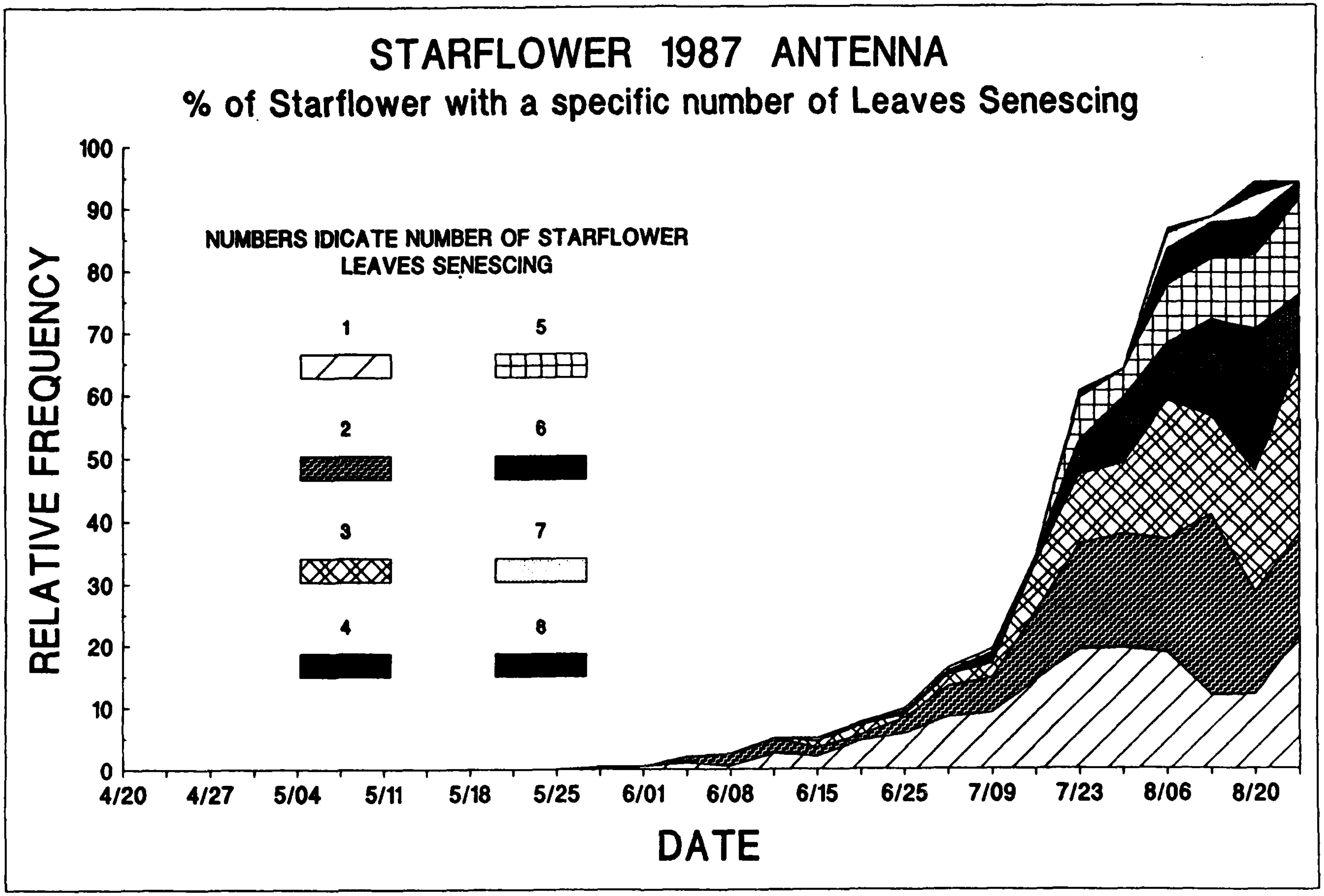

STARFLOWER 1987 CONTROL
Number of Fruit
RELATIVE FREQUENCY
0
10
20
30
40
50
4/20
4/27
5/04
5/11
5/18
5/25
6/01
6/08
6/15
6/25
7/09
7/23
8/06
8/20
DATE
1
2

Figure 3.7



STARFLOWER 1987 ANTENNA
% of Starflower with a specific number of Leaves Senescing
RELATIVE FREQUENCY
0
10
20
30
40
50
60
70
80
90
100
NUMBERS IDICATE NUMBER OF STARFLOWER LEAVES SENESCING
1
2
3
4
5
6
7
8
4/20
4/27
5/04
5/11
5/18
5/25
6/01
6/08
6/15
6/25
7/09
7/23
8/06
8/20
DATE

Figure 3.8

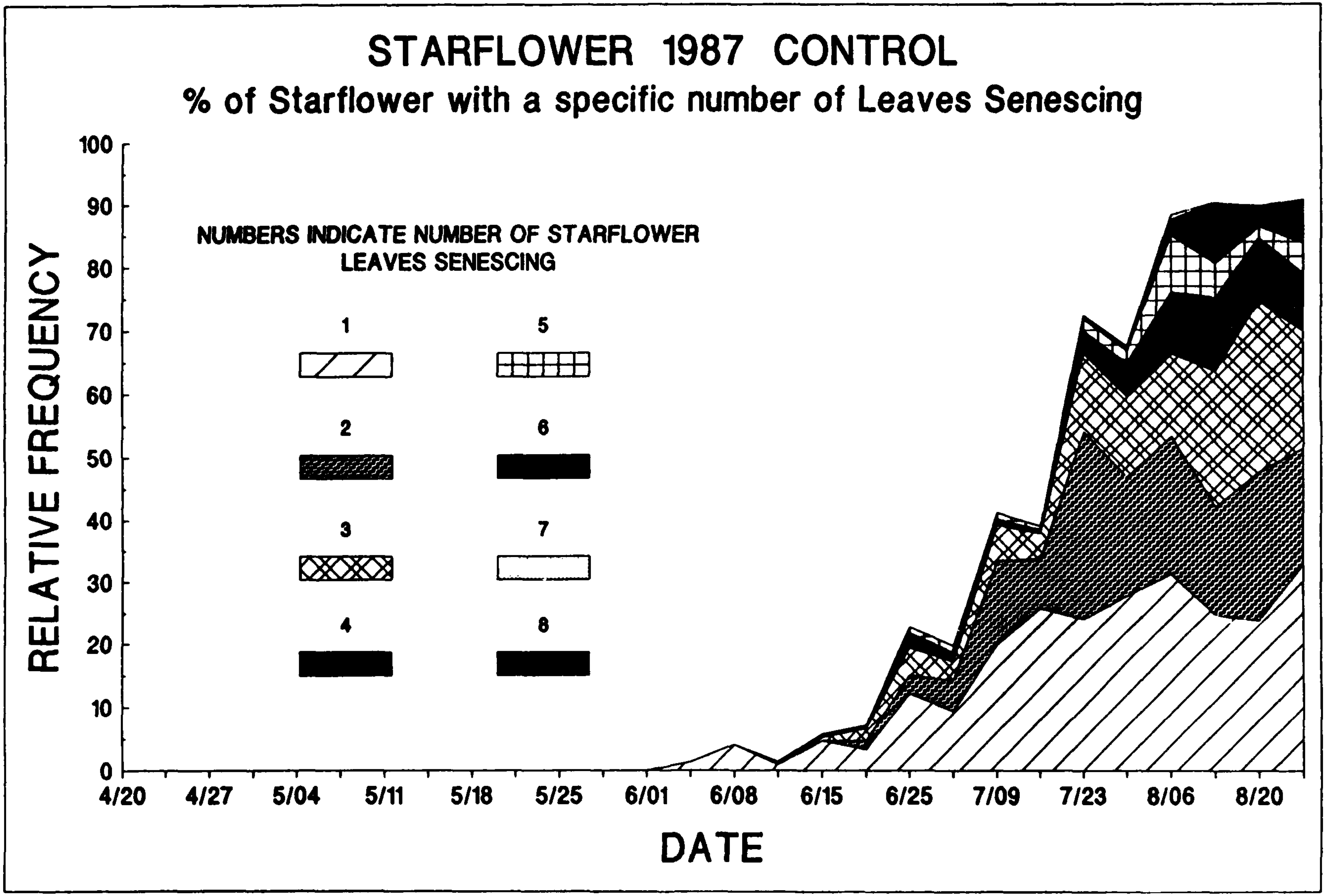
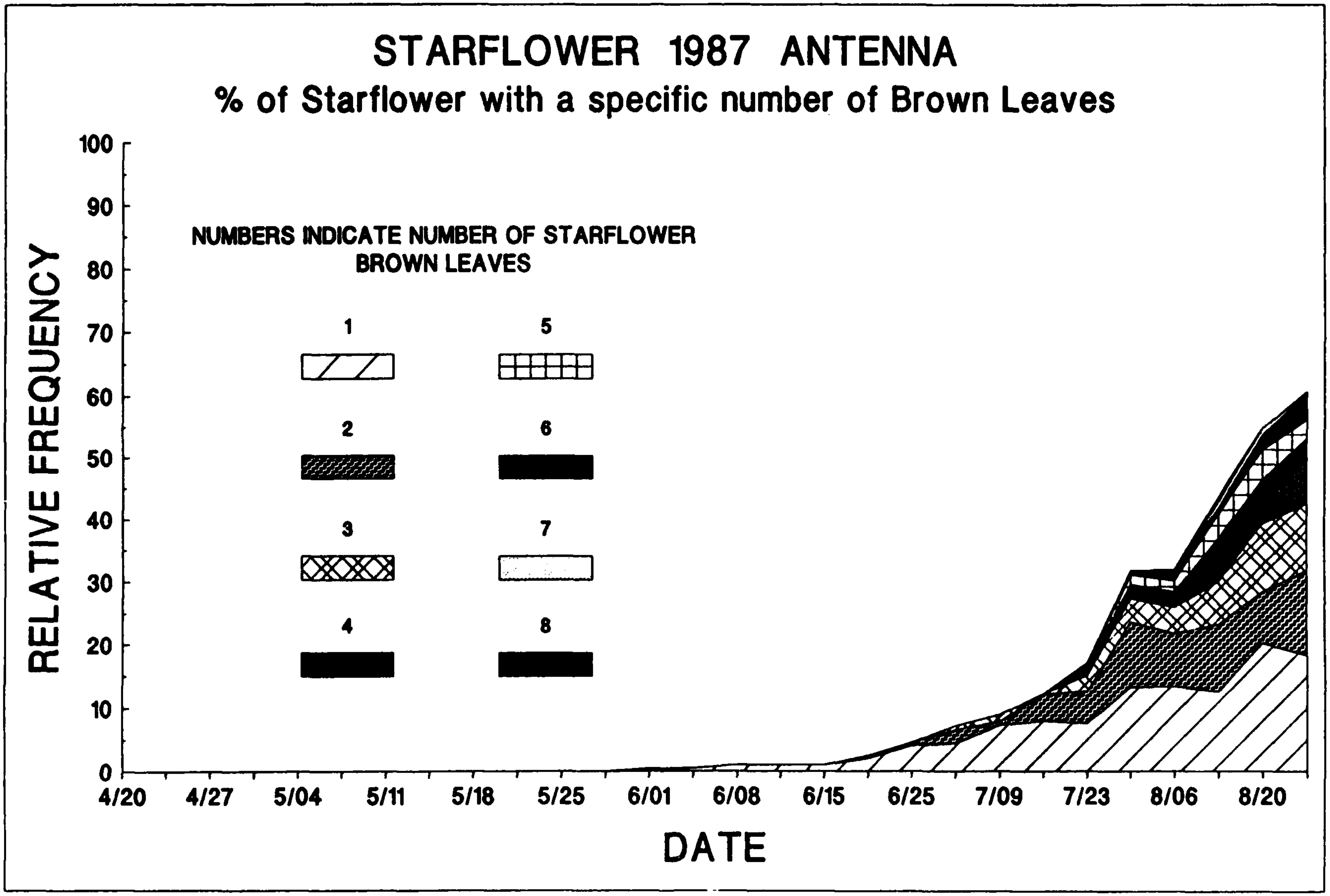
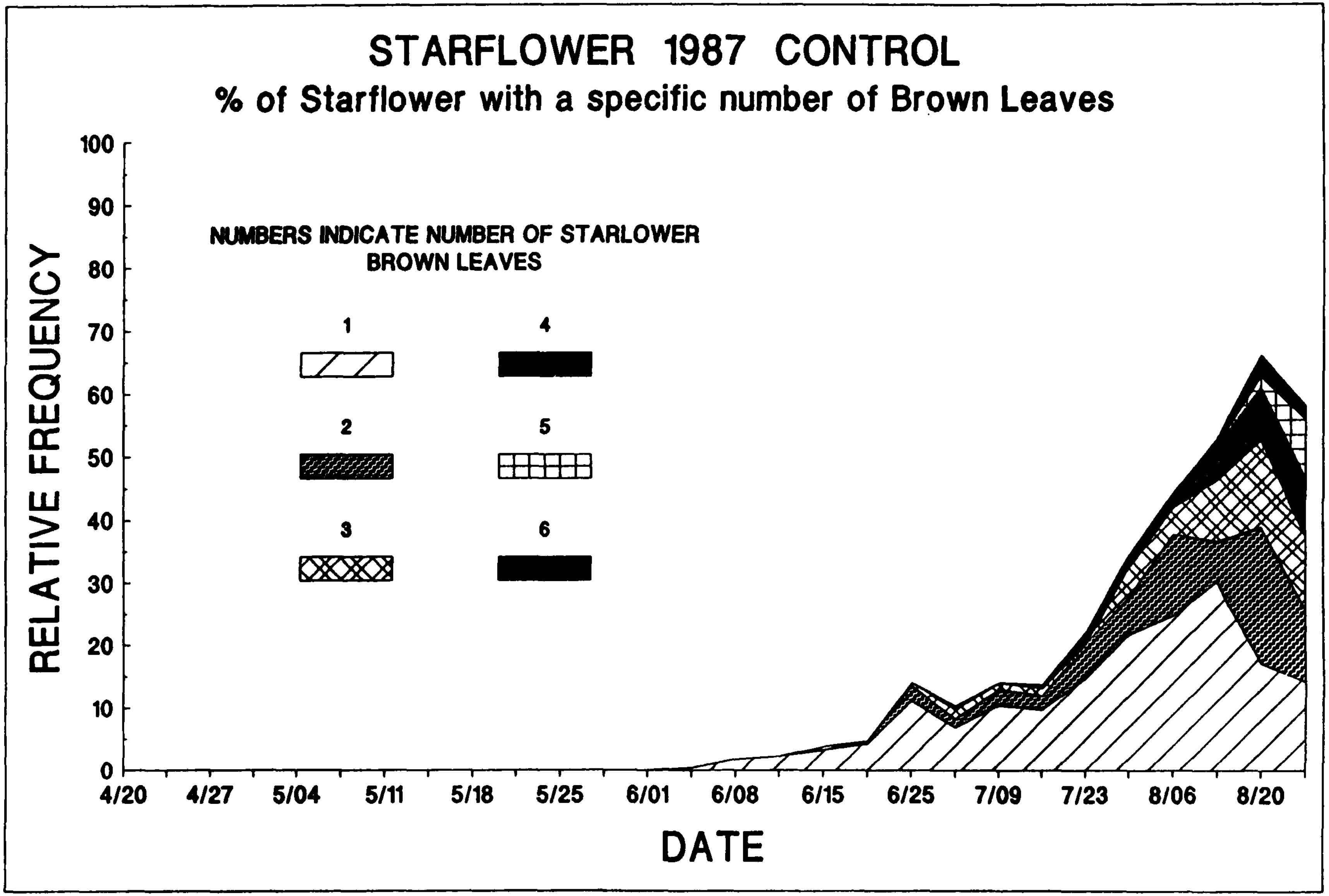

STARFLOWER 1987 CONTROL
% of Starflower with a specific number of Leaves Senescing
NUMBERS INDICATE NUMBER OF STARFLOWER LEAVES SENESCING
1
2
3
4
5
6
7
8
RELATIVE FREQUENCY
0
10
20
30
40
50
60
70
80
90
100
DATE
4/20
4/27
5/04
5/11
5/18
5/25
6/01
6/08
6/15
6/25
7/09
7/23
8/06
8/20

Figure 3.9



STARFLOWER 1987 ANTENNA
% of Starflower with a specific number of Brown Leaves
RELATIVE FREQUENCY
100
90
80
70
60
50
40
30
20
10
0
NUMBERS INDICATE NUMBER OF STARFLOWER BROWN LEAVES
1
2
3
4
5
6
7
8
4/20
4/27
5/04
5/11
5/18
5/25
6/01
6/08
6/15
6/25
7/09
7/23
8/06
8/20
DATE

Figure 3.10



STARFLOWER 1987 CONTROL
% of Starflower with a specific number of Brown Leaves
RELATIVE FREQUENCY
100
90
80
70
60
50
40
30
20
10
0
NUMBERS INDICATE NUMBER OF STARLOWER BROWN LEAVES
1
2
3
4
5
6
4/20
4/27
5/04
5/11
5/18
5/25
6/01
6/08
6/15
6/25
7/09
7/23
8/06
8/20
DATE

degree day running total indicated that the variation in the response variables increased with increasing soil temperature (e.g. non-constant variance). This problem was solved by taking the natural log of soil temperature degree day running total. Precipitation running totals were highly correlated with the response variables ($0.20<r<0.50$) but were also highly correlated with the natural log of soil temperature degree day running total. Thus, precipitation was not used in the analysis. Minimum relative humidity and soil moisture content at 5 cm were instead tested in the analysis since they explained significant variation in the response variables but were not highly correlated with the natural log of soil temperature degree days running total. These variables did not exhibit non-constant variance and thus transformation was not applied.

When the natural log of soil temperature degree days running total at 5 cm was added into the analysis, it explained significant amounts of variation in leaf area between sites, among years and site by years (Table 3.1A). Significant differences in stem expansion and leaf expansion were still evident between sites, among years and year by sites. Soil moisture content at 5 cm was then added to the analysis (Table 3.1B). With the addition of soil moisture, significant differences in stem expansion and leaf expansion between sites and among sites by years were explained. With the addition of minimum relative humidity, significant differences among years was explained (Table 3.1C).

In observing the phenological events of flowering and fruiting for both sites, each event began when the previous event was at its maximum (Figure 3.11 and 3.12), indicating that the capacity for a certain event to begin is related to the energy required to perform the former event. Since it is possible that ELF fields could affect the relationships of these events, statistical analysis next year will be concerned with determining if predictions can be made of starflower's phenological events based on the timing of the prior event. At this time, differences in the relationships of phenological events between the antenna and control sites cannot be discerned. Additional analyses will be done in the next year to determine if their are differences in the actual dates that an individual plant initiates leaf expansion, bud set, flowering, fruiting, and leaf senescence between the antenna and control site among years.

Table 3.1. Results of ANCOVA (p values) to determine significant differences in stem expansion (STEM), leaf expansion (LGTH), and leaf area expansion (LAREA) between sites, years, and years by site.

A) Covariate - Natural Log (Soil Temperature Degree Days Running Total)

Source of Variation	STEM	LGTH	LAREA
Year	0.03	NS	NS
Site	0.02	0.01	NS
Site by Year	0.04	0.02	NS

B) Covariates - Natural Log (Soil Temperature Degree Days Running Total)
+ Soil Moisture Content (5 cm)

Source of Variation	STEM	LGTH	LAREA
Year	0.01	NS	0.03
Site	NS	NS	NS
Site by Year	NS	NS	NS

C) Covariates - Natural Log (Soil Temperature Degree Days Running Total)
+ Soil Moisture Content (5 cm)
+ Minimum Relative Humidity

Source of Variation	STEM	LGTH	LAREA
Year	0.01	NS	NS
Site	NS	NS	NS
Site by Year	NS	NS	NS

NS = not significant at $p < 0.05$.

Figure 3.11

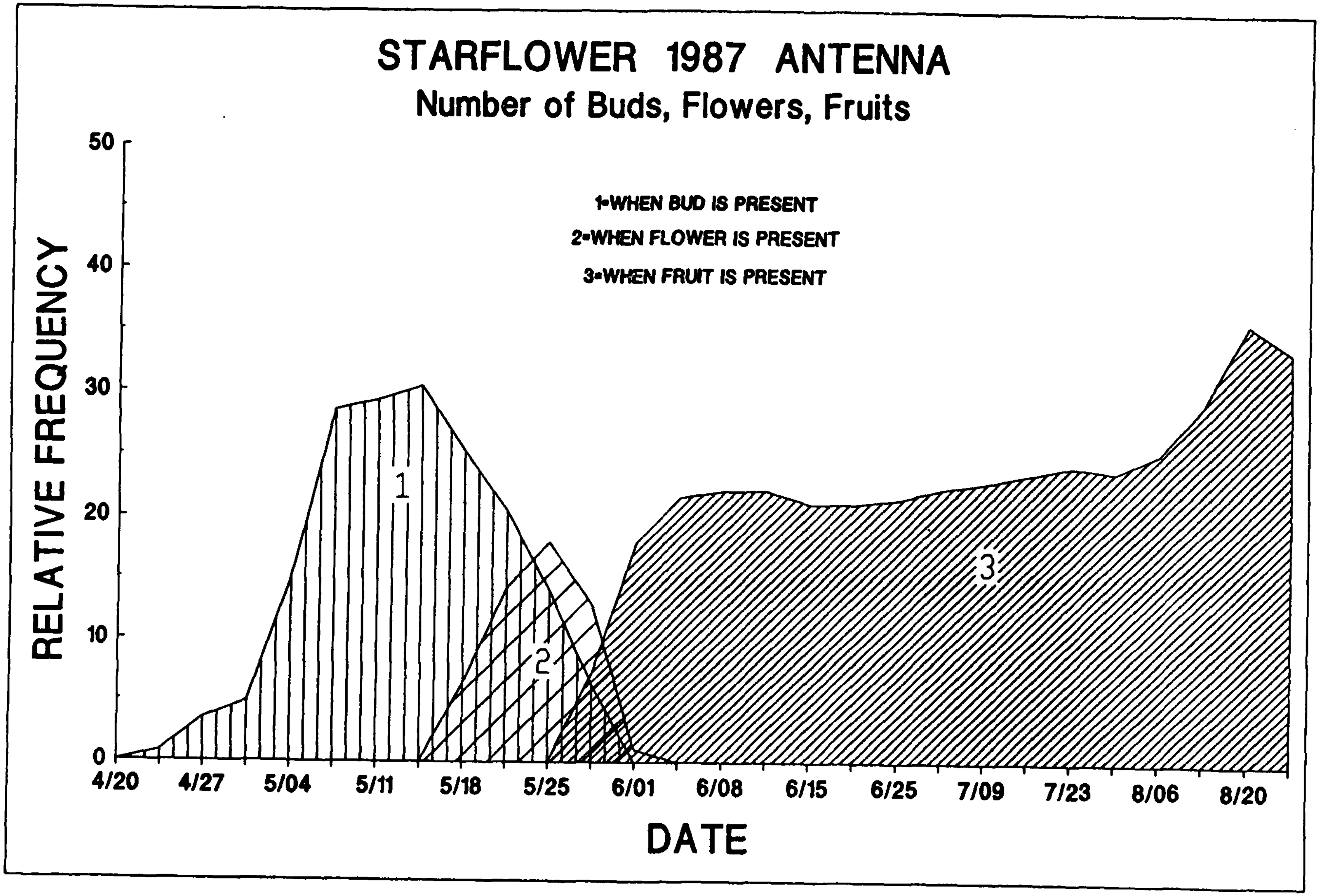
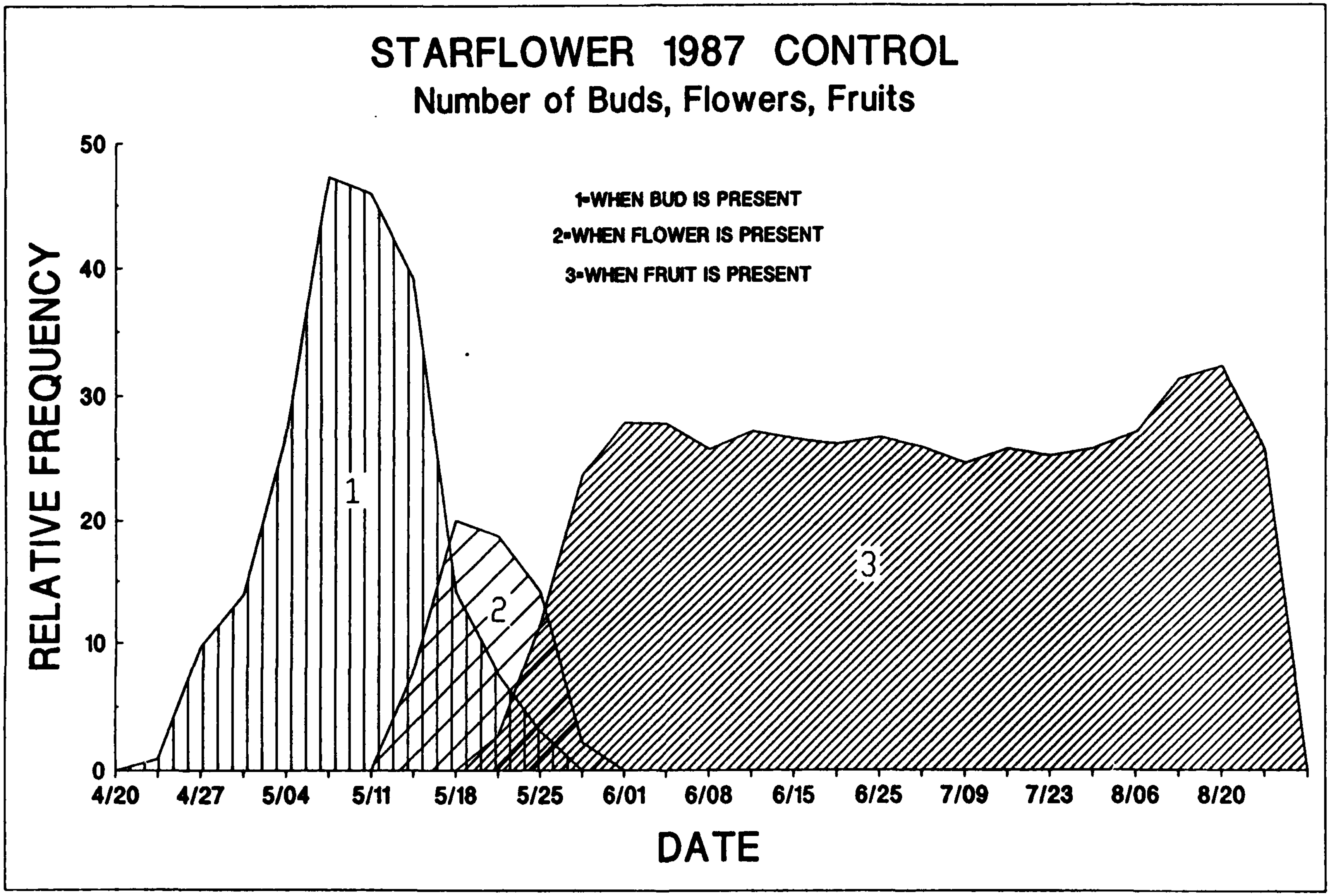

STARFLOWER 1987 ANTENNA
Number of Buds, Flowers, Fruits
1=WHEN BUD IS PRESENT
2=WHEN FLOWER IS PRESENT
3=WHEN FRUIT IS PRESENT
RELATIVE FREQUENCY
0
10
20
30
40
50
1
2
3
4/20
4/27
5/04
5/11
5/18
5/25
6/01
6/08
6/15
6/25
7/09
7/23
8/06
8/20
DATE

Figure 3.12


STARFLOWER 1987 CONTROL
Number of Buds, Flowers, Fruits
1=WHEN BUD IS PRESENT
2=WHEN FLOWER IS PRESENT
3=WHEN FRUIT IS PRESENT
RELATIVE FREQUENCY
0
10
20
30
40
50
1
2
3
4/20
4/27
5/04
5/11
5/18
5/25
6/01
6/08
6/15
6/25
7/09
7/23
8/06
8/20
DATE

Morphological Characteristics

In 1987, stem length, leaf length, and leaf width were significantly greater on the antenna site than on the control site (Figure 3.1). While more buds (> 2 buds per plant) were observed on plants on the antenna site versus the control site (Figure 3.3), more plants produced buds on the control site than on the antenna site (Figure 3.3). The amount of plants that produced flowers were about the same on the antenna and the control site as was the number of flowers per plant (Figure 3.4). More fruit (>2 fruits per plant) were observed on plants on the antenna site than on the control site (Figures 3.5 and 3.6). However, as with the number of buds, more plants produced fruit on the control site than on the antenna site. The antenna and control sites exhibited the same amount of plants that produced yellow and brown leaves (Figures 3.7 and 3.8). Similar relationships were seen in the 1985 and 1986 growing season (Appendix C).

Using regression analysis, linear equations were fit to observations of leaf area using leaf length and leaf width measured on destructively sampled starflower plants off the herbaceous reserves for each year (1986 and 1987) on each site (Table 3.2). The independent variable of leaf width x leaf length explained 99 percent of the variation in leaf area for all equations.

Table 3.2. Leaf area (LA) equations for each site in each year and for all sites and all years using leaf width (Lw) and leaf length (Ll).

Control Site (1986)	LA = 0.09 + 0.55 (Lw x Ll)
Control Site (1987)	LA = 0.11 + 0.56 (Lw x Ll)
Antenna Site (1986)	LA = 0.13 + 0.55 (Lw x Ll)
Antenna Site (1987)	LA = 0.13 + 0.56 (Lw x Ll)
All Sites/All Years	LA = 0.11 + 0.56 (Lw x Ll)

The coefficients (intercepts) were tested to determine if there were significant differences ($p = 0.05$) between the antenna site and the control site between the 1986 and 1987 growing seasons. Although the intercepts for the antenna sites are greater than the control sites for both 1986 and 1987, no significant differences in coefficients between sites ($p = 0.81$) nor among sites by years ($p = 0.51$) were found. Thus, one equation was used for both the antenna site and control site for all years to estimate maximum leaf area

for the observations on individual starflower plants (Table 3.1). Ninety-nine percent of the variation in leaf area was explained using leaf width x leaf length for all sites and all years. Since significant differences were not found between equations developed for leaf area of starflower on the antenna site versus equations for the control site, the ELF fields that occurred in 1987 have not significantly affected the leaf morphology of starflower.

Summary

At this time, significant variation in stem expansion, leaf expansion, and leaf area expansion between the antenna and the control site can be explained using soil temperature degree day running total at 5 cm, soil moisture content at 5 - cm, and minimum relative humidity. The ELF fields in 1987 did not seem to affect starflower's leaf and stem expansion nor its leaf area expansion. Additional analyses on the relationship of each event to the prior event will be done in the next year. Additional analyses will also be done to determine if the actual dates that a plant begins to set buds, flower, set fruit, produce yellow and brown leaves differ by site, years or year within site. Monitoring of starflower's morphological characteristics between sites will continue.

Element 4: HERBACEOUS VEGETATION COVER

Disturbances, whether anthropogenic or natural, can influence the structure and diversity of forest plant populations. One of the most fragile units in a forested ecosystem is the herbaceous plant population, often being more sensitive to perturbations than the overstory. Its function in the ecosystem includes its role in nutrient cycling and availability as a food source for fauna and microfauna. Thus, disturbances that reduce the diversity and number of herbaceous plants in an ecosystem, can affect the diversity and number of other forest components. For this reason, perturbations, such as ELF fields, need to be evaluated and monitored.

The objectives of this element are to 1) collect and evaluate data on the frequency and coverage of herbaceous plants on selected plots within the ELF antenna and control sites prior to and during operation of the ELF antenna, and 2) determine if changes in the diversity, frequency, and coverage of herbaceous plants occur due to ELF electromagnetic fields. Since the composition of herbaceous plant communities has been found to be influenced by environmental changes, ELF fields may cause changes in the diversity and abundance of herbaceous plant species. Changes in 1) number of species, 2) species composition, and 3) importance of individual species may indicate the effects of ELF fields on the herbaceous community. Thus, the magnitude and direction of any changes will be considered in this work. Trends in species composition over time will be monitored on a yearly basis so that changes in herbaceous cover and total number of plants can also be assessed.

Sampling and Data Collection

Late-season species, such as Aster macrophyllus, are not present on the sites until late July. To account for this, field work was conducted in early August when species diversity and plant biomass are the greatest. Percent cover and frequency of herbaceous plant species were obtained on four randomly located 1-m^2 subplots along three permanently marked transects within each plot on the undisturbed herbaceous plant reserves (4 subplots x 3 transects x 3 plots = 36 total subplots) (Figure 4.1). On the red pine plantations with weed control, four randomly located subplots along one permanently marked transect within each plot were measured for percent cover and frequency (4 subplots x 1 transect x 3 plots = 12 subplots). Similarly, 12 subplots were also randomly located on the red pine plantation in an area adjacent to the weed control plots that were not subjected to weed control measures. Although recently harvested sites are "unstable" or rebounding ecosystems, we feel that the effects of ELF on these systems should still be

Figure 4.1

HERBACEOUS PLANT TRANSECTS
Frequency and Coverage

Herbaceous Reserve Plots

```
     Plot 333           Plot 332           Plot 331
¶-----------------¶-----------------¶-----------------¶
¶                 ¶                 ¶                 ¶
¶......3331.......¶......3321.......¶.......3311......¶
¶                 ¶                 ¶                 ¶
¶......3332.......¶......3322.......¶.......3312......¶
¶                 ¶                 ¶                 ¶
¶......3333.......¶......3323.......¶.......3313......¶
¶                 ¶                 ¶                 ¶
¶-----------------¶-----------------¶-----------------¶
```

Plantation plots

```
      Plot 313          Plot 312            Plot 311
¶-----------------¶-----------------¶-----------------¶
¶                 ¶                 ¶                 ¶
¶                 ¶                 ¶                 ¶
¶                 ¶                 ¶                 ¶
¶......3131.......¶......3121.......¶.......3111......¶
¶                 ¶                 ¶                 ¶
¶                 ¶                 ¶                 ¶
¶                 ¶                 ¶                 ¶
¶-----------------¶-----------------¶-----------------¶
```

Transects outside plantation plots (clearcut)

```
¶......3143.......¶......3142.......¶......3141.......¶
```

monitored. Statistical techniques such as discriminant analysis may also allow us to evaluate the relative changes in importance of certain species between the antenna and control plantation sites with age.

The following percent coverage classes were used to estimate coverage for all herbaceous species present:

Coverage Class	% Coverage
1	0-.4
2	.5-.9
3	1-5
4	6-15
5	16-35
6	36-65
7	66-95
8	96-100

Midpoints of the percent cover classes were used to determine percent cover. Relative cover, relative frequency, and importance values were calculated for each species on each plot and transect using the following calculations:

$$\text{Relative Cover (\%)} = \frac{\text{Percent cover of species "A"} \times 100}{\text{Total cover}}$$

$$\text{Relative Frequency (\%)} = \frac{\text{\# of subplots "A" present in} \times 100}{\text{4 subplots}}$$

$$\text{Importance Value} = \underline{\text{Relative frequency + relative cover}}$$

Progress

Analysis

We have focused our efforts this year on 1) evaluating changes in a species importance values on each site for the first three years (1985, 1986, and 1987) and 2) using discriminant analysis to determine if ELF fields affect the importance of herbaceous species on these sites.

To evaluate the sensitivity of herbaceous vegetation to disturbance, discriminant analysis was used to: 1) develop functions using species importance values from pretreatment years (1985 and 1986) and 2) determine if discriminant functions from 1985 or 1986 could be used to predict or correctly classify plots on the ELF antenna site versus plots on the control site after the ELF antenna becomes operational. The assumption with this analysis is that changes in species importance values (i.e., species used in the discriminant function), will affect the discriminant function's ability to correctly classify plots on these sites. The observed misclassification rates were analyzed in relation to the

results expected by chance (e.g., two groups with equal probability of assigning cases would have an expected misclassification rate of 50%). Discriminant functions having a misclassification rate of 50% or greater are doing no better than chance. Thus, misclassification rates greater than or equal to 50% is the criteria we have chosen to indicate major changes in herbaceous plant composition due to ELF fields.

Individual discriminant functions were developed for 1985 and 1986 datasets on the A) herbaceous reserves, B) red pine plantation - weed control, and C) red pine plantation - no weed control. Discriminant functions were evaluated based on 1) the canonical correlation coefficient or the measure of association between the discriminant scores and the groups (ELF vs Control), 2) Box's M statistic - a statistic that tested whether the covariance matrices between groups were dissimilar, and 3) the number of cases correctly classified using the discriminant function.

Herbaceous Reserves

Importance Values

Importance values and ranks for the most important shrubs and herbs were calculated for each years data (Table 4.1). In 1985, Corylus spp., Gaultheria procumbens, and Pteridium aquilinum were the three most important species on the antenna site. Pteridium aquilinum, Trientalis borealis, and Aster macrophyllus were the three most important species on the control site. In 1986, the same three species on each site were still most important (Table 4.1). In 1987, the same three species on the antenna site were still the most important. However, Waldsteinia fragarioides replaced Aster macrophyllus as one of the three most important species on the control site.

A decrease of more than 10% in importance values (our criteria for analyzing significant changes in importance values) for Oryzopsis asperifolia, Carex umbellata, Diervilla lonicera occurred between 1986 and 1987 at the antenna. At this time, reasons for this response are not known. This response could be due to changes in weather patterns between 1986 and 1987 or to intermittent ELF fields transmitted during summer, 1987.

Discriminant Analysis

Discriminant functions were developed using species common on both the antenna and the control site. In the initial analysis of the 1985 dataset, a stepwise forward selection procedure was based on the change in Rao's V (Lawley-Hotelling trace) and a significance level pf p=0.05 for entry. Corylus spp., Gaultheria procumbens, Maianthemum

Table 4.1 Importance values (ranks) for the most important species on the herbaceous reserves for three years at the antenna and control sites.

	1985		1986		1987	
SPECIES	Antenna	Control	Antenna	Control	Antenna	Control
Corylus spp.	136.7(1)	47.6(7)	117.1(1)	67.7(4)	120.7(1)	61.1(4)
Pteridium aquilinum	76.2(3)	95.4(1)	104.5(2)	118.8(1)	101.0(2)	100.0(1)
Gaultheria procumbens	93.1(2)	41.6(8)	79.4(3)	39.5(8)	82.7(3)	44.9(8)
Aster macrophyllus	49.3(4)	77.1(3)	39.3(4)	80.1(2)	39.4(4)	52.0(6)
Rubus allegheniensis	-------	-------	32.9(6)	0.0	33.5(7)	39.8(9)
Vaccinium membranaceum	33.8(5)	14.7(12)	27.9(7)	25.5(12)	27.5(8)	24.3(11)
Trientalis borealis	22.9(6)	90.7(2)	37.8(5)	70.1(3)	38.6(5)	88.7(2)
Rubus parviflorus	10.2(7)	0.0	16.9(11)	0.0	10.6(12)	0.0
Anemone quinguefolia	19.9(8)	56.3(6)	14.0(12)	8.4(15)	11.1(11)	22.5(12)
Rubus idaeus	17.4(9)	18.9(11)	7.6(16)	31.1(11)	34.4(6)	0.0
Oryzopsis asperifolia	17.2(10)	65.4(4)	25.8(8)	51.5(7)	6.0(13)	45.5(7)
Carex umbellata	14.4(11)	0.0	23.4(9)	0.0	0.0	3.0(13)
Prunus pennsylvanica	-------	-------	17.1(10)	8.9(14)	0.0	0.0
Diervilla lonicera	17.2(10)	0.0	11.1(14)	5.9(16)	0.0	0.0
Maianthemum canadense	8.7(12)	56.9(5)	11.3(13)	60.0(5)	11.1(10)	55.2(5)
Lycopodium obscurum	0.0	38.4(9)	0.0	31.3(10)	18.9(9)	0.0
Aralia nudicaulis	0.0	37.7(10)	0.0	35.9(9)	0.0	30.5(10)
Waldsteinia fragarioides	0.0	0.0	0.0	53.6(6)	0.0	62.9(3)
Amelanchier spp.	0.0	11.8(13)	8.4(15)	14.5(13)	2.9(14)	0.0

canadense, Rubus idaeus, and Trientalis borealis were chosen as the linear combination that "best" separated the antenna site from the control site with 100% of the plots correctly classified (Table 4.2). Using the discriminant function for 1985, information on importance values for these species on each plot were used to classify the antenna and control sites in 1986 and 1987. Eighty-three percent of the plots were correctly classified in 1986, while 72.2% of the plots in 1987 were correctly classified (Table4.2).

Table 4.2. Classification results using discriminant analysis for 1985 importance values for Corylus spp., Gaultheria procumbens, Maiainthemum canadense, Rubus idaeus, and Trientalis borealis on the herbaceous reserves.

	1985	1986	1987
Canonical correlation	.96	----	----
Overall classification (%)	100	83.3	72.2
Classification - Antenna (%)	100	77.8	66.7
Classification - Control (%)	100	88.9	77.8
Box's M - significance level	.53	----	----

Since phenological information on Trientalis borealis is being used as an indicator of ELF effects, a discriminant function, using only importance values from T. borealis, was also developed for the herbaceous reserves (Table 4.3).

Table 4.3. Classification results using discriminant analysis for 1985 importance values for Trientalis borealis, only on the herbaceous reserves.

	1985	1986	1987
Canonical correlation	.76	----	----
Overall classification (%)	94.4	61.1	77.8
Classification - Antenna (%)	100	77.8	66.7
Classification - Control (%)	88.9	44.4	88.9
Box's M - significance level	.29	----	----

Using this function, 61.1% of the plots were classified correctly in 1986, while 77.8% of the plots were classified correctly in 1987. These results indicate that discriminant functions developed in 1985, classified the antenna and control sites with better than 50% chance. These results also indicate that intermittent ELF fields in 1987 did not significantly affect the classification of the antenna and

control sites using information from 1985. Discriminant functions developed from 1986 data using the same species produced similar classification results for 1987.

Red Pine Plantation - Weed Control

Importance Values

Importance values and ranks for the most important shrubs and herbs were calculated for each years data on these plantations (Table 4.4). Weed control was not completed until mid-summer 1986, before herbaceous species were sampled. Thus, comparisons of species composition for this section is limited to 1986 and 1987. Pteridium aquilinum, Carex umbellata, and Oryzopsis asperifolia were the three most important species on the antenna in 1986 and in 1987. Rubus allegheniensis, Aster macrophyllus, and Pteridium aquilinum were the three most important species on the control in 1986 and in 1987. Significant decreases (>10%) in importance values did not occur for any species at the antenna between 1986 and 1987. A significant decrease (>50%) in Oryzopsis asperifolia did occur on the control. This may indicate that 1) climate may have had an affect on the coverage and frequency of this species during 1987 or 2) the processes of succession will eliminate this species. We do not know at this time whether reduced levels of one species on the plantations from one year to the next indicates that the site is returning to the species composition of the herbaceous reserves. However, index-free diversity orderings (Swindel et al., 1987) may provide a means of analyzing these effects. Swindel et al. (1987) demonstrated the use of diversity orderings in comparing the convergence or divergence of species diversity on sites having two different regeneration regimes.

Discriminant Analysis

Discriminant functions were developed using information from 1986, since weed control did not occur until 1986. Aster macrophyllus was the only species chosen in the discriminant analysis that "best' separated the antenna from the control site (Table 4.5)

Table 4.4 Importance values (ranks) for the most important species on the red pine plantations with weed control (1986) for three years at the antenna and control sites.

SPECIES	1985* Antenna	1985* Control	1986 Antenna	1986 Control	1987 Antenna	1987 Control
Pteridium aquilinum	130.6(1)	114.1(2)	115.5(1)	104.1(2)	142.7(1)	96.8(3)
Gaultheria procumbens	71.2(3)	25.1(10)	0.0	16.8(10)	58.4(5)	8.3(14)
Crataegus spp.	44.4(7)	35.4(6)	0.0	0.0	43.2(7)	87.9(4)
Diervilla lonicera	54.2(5)	0.0	0.0	0.0	0.0	0.0
Carex umbellata	81.1(2)	31.7(7)	90.1(2)	72.2(5)	85.4(3)	86.1(5)
Oryzopsis asperifolia	.56.3(4)	60.6(3)	78.9(3)	79.8(4)	66.8(4)	28.4(10)
Rubus allegheniensis	0.0	0.0	19.3(8)	127.2(1)	53.5(6)	124.7(1)
Polygonum cilinoide	0.0	0.0	0.0	0.0	0.0	0.0
Vaccinium membranaceum	46.0(6)	17.7(11)	36.2(5)	9.0(11)	87.1(2)	25.2(11)
Rubus parviflorus	13.7(12)	0.0	32.1(6)	0.0	16.7(10)	0.0
Prunus pennsylvanica	0.0	16.8(12)	45.2(4)	34.1(8)	42.8(8)	34.4(9)
Panicum implicatum	26.0(10)	8.3(14)	0.0	0.0	0.0	0.0
Trientalis borealis	17.4(11)	0.0	16.7(9)	0.0	16.7(10)	16.7(12)
Waldsteinia fragarioides	9.0(13)	55.1(4)	0.0	25.5(9)	0.0	69.5(6)
Lycopodium obscurum	0.0	25.6(9)	0.0	50.3(6)	0.0	0.0
Aster macrophyllus	35.6(8)	120.4(1)	8.3(10)	96.2(3)	8.4(12)	104.4(2)
Maianthemum canadense	9.0(13)	51.0(5)	0.0	42.4(7)	0.0	66.9(7)
Comptonia peregrina	26.3(9)	25.8(8)	26.4(7)	8.4(12)	8.6(11)	34.6(8)
Amelanchier spp.	0.0	8.5(13)	0.0	16.8(10)	25.5(9)	8.5(13)

* - no weed control

Table 4.5. Classification results using discriminant analysis for 1986 importance values for Aster macrophyllus, only on the plantation with weed control.

	1986	1987
Canonical correlation	.96	----
Overall classification (%)	100	100
Classification - Antenna (%)	100	100
Classification - Control (%)	100	100
Box's M - significance level	.97	----

Importance values for Aster macrophyllus in 1987 were used in the discriminant function with 100% of the plots correctly classified (Table 4.5). Because of the high relative dominance of Aster on the plantations, discriminant functions may not provide the necessary information on the possible effects of ELF on other herbaceous species. The "unstable" or rebounding nature of the plantation plots may limit the application of any statistical method. Analysis using diversity orderings versus discriminant functions to monitor the effects of ELF on the plantation areas however, will be evaluated in the coming year.

Red Pine Plantations - No Weed Control

<u>Importance values</u>

Importance values and ranks for the most important shrubs and herbs were calculated for each year data (Table 4.6). One year after harvesting (1985), Pteridium aquilinum, Gaultheria procumbens, and Crataegus spp. were the three most important species on the antenna site. Aster macrophyllus, Pteridium aquilinum, and Waldsteinia fragiodes were the three most important species on the control site. In 1986 or two years after harvesting, a major shift in the importance of certain species occurred; Carex umbellata, Pteridium aquilinum, and Prunus pennsylvanica were the three most important species on the antenna site. Rubus allegheniensis, Aster macrophyllus, and Pteridium aquilinum were the three most important species on the control site. In 1987, the three most important species on the control site stayed the same, while Pteridium aquilinum, Carex umbellata and Rubus allegheniensis were the three most important species on the antenna site. A significant decrease (>10%) in importance values for Panicum implicatum and Trientalis borealis occurred between 1986 and 1987 on the antenna site (Table 4.6). However, these two

Table 4.6 Importance values (ranks) for the most important species on the red pine plantations without weed control for three years at the antenna and control sites

SPECIES	1985 Antenna	1985 Control	1986 Antenna	1986 Control	1987 Antenna	1987 Control
Pteridium aquilinum	93.7(1)	114.4(2)	111.9(2)	79.8(3)	110.7(1)	131.6(1)
Gaultheria procumbens	70.3(2)	34.1(9)	25.1(11)	17.2(14)	25.6(10)	25.0(11)
Crataegus spp.	69.5(3)	52.7(4)	-------	-------	16.8(12)	62.3(6)
Diervilla lonicera	68.2(4)	0.0	8.3(15)	25.5(13)	0.0	0.0
Carex umbellata	64.9(5)	52.4(5)	114.2(1)	56.2(6)	76.8(3)	74.1(5)
Oryzopsis asperifolia	58.6(6)	36.2(8)	46.2(5)	78.0(4)	59.9(4)	55.1(7)
Rubus allegheniensis	-------	-------	44.4(6)	130.9(1)	93.8(2)	111.6(2)
Polygonum cilinoide	45.6(7)	8.6(11)	48.7(4)	0.0	51.4(6)	0.0
Vaccinium membranaceum	44.8(8)	44.0(7)	25.4(9)	26.9(10)	35.6(8)	25.6(10)
Rubus parviflorus	43.0(9)	0.0	43.1(7)	0.0	45.4(7)	0.0
Prunus pennsylvanica	-----	-----	63.7(3)	25.6(12)	59.8(5)	17.7(12)
Panicum implicatum	29.8(10)	8.3(12)	26.2(8)	8.6(15)	0.0	0.0
Trientalis borealis	27.0(11)	0.0	25.3(10)	8.4(16)	0.0	0.0
Waldsteinia fragarioides	0.0	71.3(3)	0.0	60.1(5)	0.0	85.6(4)
Lycopodium obscurum	0.0	51.2(6)	8.4(14)	42.4(8)	0.0	0.0
Aster macrophyllus	17.4(13)	131.3(1)	17.0(12)	91.1(2)	33.8(9)	110.43(3)
Maianthemum canadense	0.0	44.0(7)	0.0	25.7(11)	0.0	50.2(8)
Comptonia peregrina	25.0(12)	25.0(10)	16.9(13)	47.0(7)	25.1(11)	29.1(9)
Amelanchier spp.	0.0	8.3(12)	0.0	33.6(9)	8.5(13)	0.0

species also decreased (< 10%) in importance on the control sites. Changes in the presence of these species is probably due to successional processes.

Discriminant Analysis

Discriminant functions were developed using species importance values from 1985. Aster macrophyllus and Panicum implicatum were chosen as the linear combination that "best" separated the antenna site from the control site. Using the 1985 discriminant function, 83.3% of the plots in 1986 were correctly classified (Table 4.7).

Table 4.7. Classification results using discriminant analysis for 1985 importance values for Aster macrophyllus and Panicum implicatum, only.

	1985	1986	1987
Canonical correlation	.99	----	----
Overall classification (%)	100	83.3	83.3
Classification - Antenna (%)	100	100	66.7
Classification - Control (%)	100	66.7	100
Box's M - significance level	.76	----	----

Although Panicum implicatum was not found on both the antenna and control sites in 1987, 83.3% of the plots were classified correctly. When a discriminant function was developed for the 1986 data (using only Aster macrophyllus), 83.3% of the plots in 1987 were still classified correctly.

Summary

At this time, we cannot conclude that ELF fields had any effect on the herbaceous species composition on the antenna site. We intend to concentrate our efforts next year on evaluating new analysis techniques, such as diversity orderings (Swindel et al., 1987), to overcome the basic problem of comparing understory species on recently harvested sites. We also believe that the use of discriminant analysis and diversity orderings will allow us to evaluate changes in species common to both sites and the relative species composition, respectively. Next year, we will be establishing permanent herbaceous plots on all sites so that a more consistent evaluation of species composition can be made on both sites from year to year.

Element 5: POPULATION DYNAMICS OF MYCORRHIZAL MACROFUNGI VIA SPOROCARP PRODUCTION

Mycorrhizae represent the integrating bridge between plant root systems and the surrounding soil. Because mycorrhizae represent a mutually beneficial relationship, they may be sensitive indicators of treatment effects on either the host or the parasite, or both. Evidence of treatment effects on either component can be weighed against possible effects on the other. Mycorrhizae are an obvious area of study for evaluation of potential ecosystem perturbations such as those associated with ELF fields.

Detailed study of ectomycorrhizae formation has been directed to the three red pine study plantations (Element 6), because of the base of existing knowledge on red pine growth and the relative ease of studying plantation seedling root systems compared to those of mature mixed hardwoods. Nevertheless, the mixed hardwood stands at the Antenna and Control sites offer an excellent opportunity to describe and quantify a portion of the indigenous ectomycorrhizal fungus community via the population dynamics of sporocarp production. Sporocarp production represents a fungal investment of energy obtained from the host in the perpetuation of the fungus species. As such, the extent of sporocarp production reflects the combined vigor of the host/parasite system. Biologically significant impacts on either host or parasite should result in adjusted fruiting patterns by the mycorrhizal fungus species involved.

The objective of this study is to use sporocarp production by selected ectomycorrhizal macrofungi indigenous to the Antenna and Ground site herbaceous reserve plots as indicators of change in hardwood stand or mycorrhizal fungus health. The overall null hypothesis proposed in this phase of the study is:

H_O: There is no difference in sporocarp production by selected mycorrhizal fungi before and after the ELF antenna becomes operational.

Sampling and Data Collection

Population dynamics of selected ectomycorrhizal macrofungi indigenous to the hardwood stands at the Antenna and Control sites are being evaluated by periodic monitoring of sporocarp production on two sets of three contiguous 30m x 35m herbaceous reserve plots. Counted sporocarps were slit vertically so that they would not be accidentally retallied during subsequent visits. Counted sporocarps were not removed, in order to minimize impact on subsequent flushes (Manachere 1985).

Because sporocarp production is closely tied to host photosynthetic activity (Last et al. 1984) and host genotype

(Last *et al.* 1984, Mason *et al.* 1984), fruiting by ectomycorrhizal macrofungi is expected to proceed as regularly as the relatively stable study stand structure and climate will permit. The large size of each study plot should reduce variability among yearly sporocarp counts by absorbing the effect among years of spatial redistribution of sporocarp production around host trees. Differences in sporocarp production among years may also be minimized by composting several years' counts for comparisons before and after the ELF antenna becomes operational. In order to explore the effects of quadrupled yet smaller sampling units on statistical power, each plot was subdivided in 1986 into four quarter plots.

Progress

Because local microclimate and host tree species (or genotype) distribution varies somewhat between the plots at each site, it is not surprising to find substantial differences in the representation of mycorrhizal fungus species among contiguous plots (1986 Annual Report, Element 5). In order to explain sporocarp distributions among the six plots, d.b.h. and species were recorded in 1987 for all hardwood stems on each plot.

Stepwise multiple linear regression is being used to explore possible relationships between the distributions of 1) host tree species (numbers of stems and basal area on each plot) and 2) sporocarps representing the populations of 32 ectomycorrhizal fungus species on each of the six plots. Because of the extra effort required by the Armillaria studies in 1987 (see Element 2), only a partial record of sporocarp production was compiled. Therefore, the analyses reported here are based on the sporocarp production records representing the six plots during 1984, 1985, and 1986. The overall significance of each regression model was evaluated using the F test for the associated analysis of variance. The predictive capability of each model is indicated by its associated r^2 value. Initial analyses were conducted on the combined fruiting records of each fungus species over the three year period, in order to minimize any variation among years due to weather, etc. Favorable initial results led to regression analysis using only the 1986 sporocarp production record.

Seven of the 32 fungus species previously selected for study show strong distributional relationships in sporocarp production to a single host tree species, both for the 1986 record and for the three year composite fruiting record (Table 5.1). Apparently strong associations occur between *Amanita brunnescens* and eastern white pine, between *amanita muscaria*, *boletus piperatus*, *Cortinarius alboviolaceus*, and *Tricholoma flavovirens* and bigtooth aspen, between Cortinarius armillatus and paper birch, and between *Russula brevipes* and northern red oak. Characteristics of the regression models derived for these relationships are presented in Table 5.1.

Table 5.1. Characteristics of regression models relating host tree species distribution on the six plots to sporocarp production by associated mycorrhizal macrofungi (based on composited fruiting records for 1984-1986).

Host Species/ Fungus Species	Equation[a]	r^2	F[b]	P[c]
eastern white pine/	Y_i = 8.458 + 5.023 EWP#	.692	22.487	.001
Amanita brunnescens	Y_i = 16.046 + 758.542 EWPBA	.818	17.950	.013
bigtooth aspen/	Y_i = -23.094 + 4.200 BTA#	.719	25.647	.001
Amanita muscaria	Y_i = -14.262 + 74.455 BTABA	.932	54.836	.002
bigtooth aspen/	Y_i = -3.864 + 1.032 BTA#	.657	19.192	.001
Boletus piperatus	Y_i = -1.334 + 18.587 BTABA	.887	31.326	.005
bigtooth aspen/	Y_i = -2.435 + 4.495 BTA#	.393	6.488	.029
Cortinarius alboviolaceus	Y_i = 26.414 + 98.312 BTABA	.945	68.935	.001
bigtooth aspen/	Y_i = -4.593 + 0.922 BTA#	.590	14.392	.004
Tricholoma flavovirens	Y_i = -3.002 + 19.175 BTABA	.986	287.391	.000
paper birch/	Y_i = -6.168 + 0.993 PB#	.384	6.236	.032
Cortinarius argillaceifolius	Y_i = -15.223 + 102.324 PBBA	.764	12.924	.023
northern red oak/	Y_i = -11.165 + 0.971 NRO#	.690	22.295	.001
Russula brevipes	Y_i = -24.560 + 44.517 NROBA	.860	24.519	.008

a/ Y_i = total sporocarp count, 1984 - 1986
EWP# = number of eastern white pine stems
EWPBA = basal area of eastern white pine
BTA# = number of bigtooth aspen stems
BTABA = basal area of bigtooth aspen
PB# = number of paper birch stems
PBBA = basal area of paper birch
NRO# = number of northern red oak stems
NROBA = basal area of northern red oak

b/ F statistic for the overall model

c/ Level of significance attained by the F statistic

Differences in host relationships among years will be evaluated by incorporating a set of classification (dummy) variables (Searle 1971) into regression models. The resulting models are identical in structure to the analysis of covariance model. The interpretation, however, can be quite different, because we are concerned with both the classification and continuous variables (analogous to covariates), while the classical analysis of covariance model used covariates only to produce more homogeneous experimental material, in order to reduce error.

Element 6. MYCORRHIZAE CHARACTERIZATION AND ROOT GROWTH

Mycorrhizae of plantation red pine seedlings have been chosen as biological components of the soil ecosystem sensitive enough to reflect perturbations which might be caused by ELF fields. Mycorrhizae are symbiotic structures representing a finely balanced physiological relationship between tree roots and specialized fungi, providing mutual benefit to both partners of the symbiosis. Mycorrhizal fungi are obligately bound to their host requiring photosynthate from the tree for their energy source. In return, the matrix of mycorrhizal fungus mycelium which permeates the forest floor from colonized roots provides the host tree with scarce minerals and water more efficiently than possible without its fungal partner. Although many types of mycorrhizae occur, this study deals only with ectomycorrhizae formed on the root systems of pine.

Mycorrhizae, being composed of two kinds of organism (though sometimes several fungi may be involved) that make up a major part of the forest ecosystem, are likely to be sensitive indicators of subtle environmental perturbations. Mycorrhizal fungi are obligate symbionts, directly dependent on their partner's physiology for their health. Thus mycorrhiza formation and numbers will be sensitive to factors affecting either their fungus parasite or the host plant component.

Mycorrhizae have been selected for evaluation in other studies which require sensitive indicators of subtle environmental changes. Recent studies designed to monitor the effects of acid rain on the forest ecosystem used mycorrhizal numbers as the parameter of assessment (Reich et al. 1985, Shafer et al. 1985, Stroo and Alexander 1985, Dighton and Skeffington 1987). Similar studies examined mycorrhizae with respect to ozone and air pollution (Kowalski 1987, Reich et al. 1985, Mejstrik and Cudlin 1987) and heavy metal buildup in soils (Jones and Hutchinson 1986). Data concerning mycorrhizae are especially valuable when collected along with other measures of plant response, such as growth and moisture stress, as is being done in this study. ELF effects not directly evoking a measurable tree response could detectably alter the more discriminating mycorrhizal fungus component. Data regarding mycorrhizae of a host tree can also be used to substantiate responses seen in other measures of tree productivity.

Populations of mycorrhizae developing at each red pine plantation site are being compared with each other at monthly intervals and with corresponding monthly intervals from previous years. The basic experimental units are individual red pine seedlings. Mycorrhizae are categorized into morphological types which are produced by different fungal associations with red pine. Changes in both the frequency of occurrence for different mycorrhizal types and the total numbers of mycorrhizae per seedling are quantified for

analysis both within and among years as well as among sites. Data for analysis are expressed as the number of mycorrhizae per gram of seedling root mass (oven dry weight (o.d.w.) 60°C). The working null hypothesis states that there are no differences in population densities of different types of mycorrhizal root tips on red pine seedlings at the Antenna, Ground and Control sites, before or after the ELF antenna becomes operational. Changes reflected by possible alternative hypotheses include, 1) shifts in population species composition, 2) increases or decreases of total mycorrhizae density, and 3) changes in character of mycorrhizal morphology type.

Sampling and Data Collection

In conjunction with Element 2, Tree Productivity, fifteen red pine seedlings per site (five per subplot replicate) were sampled for six months during the 1987 growing season, as was done the previous two years. Seedlings for mycorrhizal analysis were simultaneously measured for top growth parameters and moisture stress. To retrieve mycorrhizae-bearing lateral roots, a soil sample approximately 22 cm in diameter and 22 cm deep was excavated with a shovel adjacent to each study seedling. Red pine seedling lateral roots were extracted from this sample in the field to obtain approximately 30 to 60 cm of total root length. A single excavation usually provided the amount required, but occasionally another sample needed to be excavated at an alternate location adjacent to the seedling. Lateral roots from each seedling with adherent soil were wrapped tightly in individual plastic bags, placed in a cooler and transported to the laboratory where they were refrigerated. Within two to three days the lateral roots were rinsed first in a small volume of distilled water (1:1 water to root/soil volume) for rhizosphere pH determination, then washed gently in tap water, placed in a fresh volume of tap water and refrigerated. Approximately 0.25 g roots (fresh weight) per sample were removed at this time for actinomycete enumeration (ELF, Litter Decomposition and Microflora Study). Counting of mycorrhizal tips began immediately and was usually completed within ten days of the field sampling date.

A shallow white pan containing a small amount of water was used during the root sectioning and counting operation. The roots were cut to obtain as many 3 cm segments and as few segments less than 3 cm as possible. Branching portions were separated from segments if they were greater than 1 cm in length. Branching portions less than 1 cm were counted as part of the root segment to which they were attached. As each root segment was counted, its length, diameter and number of mycorrhizae were recorded. A mycorrhiza is defined, for counting purposes in this study, as a terminal mycorrhizal root tip at least 1.0 mm in length; hence a mature dichotomously branched mycorrhizal root tip would be tallied

as two mycorrhizae. Upon completion of counting, the root segments were collectively dried at 60°C to constant mass and weighed. Mycorrhiza counts for each seedling are expressed as mycorrhizae per gram (o.d.w.) of lateral root. This measure is used in other root studies examining mycorrhizae dynamics in forest ecosystems (Harvey et al. 1987).

Since these seedlings were grown in fumigated nursery soil, their mycorrhizae have a fairly uniform morphology. They range in color from tan to deep red-brown, are formed primarily by Thelephora terrestris and/or Laccaria laccata (sensu lato, Fries and Mueller 1984),and were designated as Type 3 mycorrhizae. Many of the mycorrhizae have acquired a nearly black to deep jet black color due to colonization by Cenococcum graniforme, an abundant mycorrhizal fungus in the original and surrounding hardwood forests,and were designated as Type 5 mycorrhizae. White to tan floccose forms are occasionally found, presumably colonized by Boletus, Hebeloma, Paxillus or Suillus spp.; these have been designated as Type 6 mycorrhizae. Though variations occur within mycorrhizal morphology types, all fit within the grouping of these three main types described. A dissecting microscope was used but was not always necessary to distinguish the mycorrhizal types. Morphology types are tallied separately and then totaled for each seedling. Non-mycorrhizal root tips are easily distinguishable as white root tips composed entirely of plant tissue, obviously lacking a fungal component.

<u>Descriptions of Red Pine Mycorrhizal Morphology Types</u>

Type 3

Macroscopic: Light buff to dark red brown, sometimes nearly black, usually lighter at the apex; 2-10 mm long x 0.25-1.0 mm diameter; mono- or bipodal, occasionally multiply bifurcated and in mass forming coralloid clusters; plump and straight when short, but spindly and often crooked when long, usually somewhat constricted at the base.

Microscopic: Surface hyphae sparse, 2-3 um diameter, bearing clamps, setae scattered, often clustered in bunches of 4-8, mostly 50-80 um long; mantle 10-20 um thick, thinner over apex, hyphae forming conspicuous interlocking, "jig-saw puzzle-like" pattern; cortical cells red-brown except over apex where they are colorless; Hartig net hyphae bulbous and also forming interlocking pattern.

Comments: This is the common and most numerous type of mycorrhiza found originally on the nursery red pine seedlings and which is still predominant. The causal fungi, as evidenced by cultural isolation, are most often Laccaria laccata (sensu lato) and Thelephora terrestris, though other fungi may also produce similar mycorrhizae. It is worth noting that L. laccata (sensu lato) abounds in the surrounding forests and fruits abundantly on the plantation sites. This fungus might therefore be expected to maintain its dominance

in the plantation seedlings. Thelephora terrestris has also been observed fruiting on the plantation sites.

Type 5

Macroscopic: Black, sometimes with lighter apex; usually fuzzy with abundant attached, coarse hyphae; 1-3 mm long x 0.5-10 mm diameter; mono or bipodal, seldom multiply bifurcated; often appearing as if dark hyphae are enveloping Type 3 mycorrhizae.

Microscopic: Surface hyphae dark-brown to black, 3-6 um diameter, septate; setae arising from central stellate points of interlocking surface hyphae, setae 100 um or greater in length; mantle 10-30 um thick, mantle surface of coiled and interlocking hyphae; cortical cells dark and covered directly with hyphae of the same type observed with Type 3 mycorrhizae; Hartig net hyphae bulbous and also with interlocking pattern.

Comments: This is a later successional stage mycorrhiza, appearing as a dark sheath over an earlier developed mycorrhiza. The causal fungus is Cenococcum graniforme, which is commonly isolated from these mycorrhizae. Hypogeous fruit bodies of Elaphomyces sp., the anamorph of C. graniforme, have been collected in the surrounding forest, indicating that adequate inoculum is available.

Type 6

Macroscopic: White to light gray-brown, mottled and silvery; 2-5 mm long x 0.5-1.0 mm diameter; abundant loosely-bound surface hyphae often binding soil matter; mono- or bipodal often in large coralloid clusters of multiply bifurcated tips; in water, air bubbles become entrapped in loose surface hyphae causing freed individual mycorrhizae to float.

Microscopic: Surface hyphae colorless, abundant, septate or not, 3-6 um diameter, multiply branched at septae; setae lacking; mantle of loose hyphae 24-100 um thick, cortical cells red-brown covered with interlocking hyphae similar to Type 3; Hartig net hyphae bulbous and also with interlocking pattern.

Comments: This also appears to be a later successional stage mycorrhiza type forming a sheath over an earlier developed mycorrhiza. Presumably the responsible fungi colonize new root tips as well. Based on cultural characteristics of isolated fungi, the causal fungi probably belong to the families Boletaceae, Cortinariaceae or Paxillaceae. Fruiting bodies of these families were common in the original forest and fruit abundantly in the surrounding forest, providing adequate and readily available inoculum.

Progress

Due to the increase in size of the seedlings and increased numbers of mycorrhizae, a subsampling method was implemented in 1985 to estimate total mycorrhizae per seedling root system. Mycorrhizae per gram of seedling root continues to be the parameter expressed, but its basis is lateral root weight rather than total root weight. The weights of unexamined lateral and tap roots were therefore subtracted from the 1985 and 1986 data to render them comparable to data of 1987 and future years.

Data of 1984 are not being compared with subsequent years for two reasons. First, 1984 was the year of plantation establishment; nursery seedlings are small and planting shock is significant. Second, there are no ambient weather or soil data available for 1984 to use in covariate analysis. Site comparisons within and between years consider the parameters of non-mycorrhizal root tips per gram, Type 3 mycorrhizae per gram, Type 5 mycorrhizae per gram, Type 6 mycorrhizae per gram, and total mycorrhizae per gram (o.d.w.) of seedling root mass. A significance level of p=0.05 with Duncan's Multiple Range Test was used to detect differences between comparable means. Comparisons among sites by month within years and among sites by years will be the primary focus of the statistical analysis.

Results

Non-mycorrhizal root tips continued to decrease on all sites in 1987, as they have in the two previous years (Table 6.1). There were no significant differences in non-mycorrhizal root tips per gram of seedling root between sites for any given month of 1987. In 1986, only one month (August) saw a significant difference between sites; the Control site being slightly higher than the Ground site. In 1985 two months (June and August) saw significant differences between sites; the Control site being higher than the Antenna site on both occasions. Nine out 13 yearly differences found that 1985 seedlings had significantly higher numbers of non-mycorrhizal root tips per gram than did those sampled in 1986 and 1987. Significant differences occurred between 1986 and 1987 only four times; each time 1987 had fewer non-mycorrhizal root tips per gram of seedling root than 1986.

When tested within the overall design of the study, considering all sites, months and years together, there were no significant differences between sites and no significant differences between years by site for non-mycorrhizal root tips per gram of seedling root. Differences occur between years and years by site because of the fact that non-mycorrhizal root tips are decreasing; 1985 seedlings had significantly higher numbers than those sampled in 1986 and 1987. The general trend shows decreasing non-mycorrhizal root tips on seedlings on all sites, which is to be expected as seedlings become established and mycorrhizal fungal inoculum density returns to uniform pre-disturbance levels.

Table 6.1 Mean and standard deviation of non-mycorrhizal root tips per gram of seedling root (o.d.w.) for red pine seedlings, 1985-1987.

	Ground		Antenna		Control	
Mo/Yr	$\bar{X}$1/	SD	$\bar{X}$	SD	$\bar{X}$	SD
May 85	10.0 c	5.7	12.0 c	9.6	10.6 c	5.1
86	4.8 d	8.7	3.3 d	4.8	1.1 d	3.4
87	2.4 d	4.2	2.7 d	5.7	0.5 d	1.6
Jun 85	5.0 AB	4.3	3.1 A	3.4	8.3 Bc	8.9
86	0.2	0.8	0.1	0.4	0 d	0
87	0	0	3.1	12.2	0.8 d	3.0
Jul 85	8.3 c	6.6	8.6 c	11.0	13.9 c	10.5
86	0.2 d	0.7	0.4 d	1.0	1.5 d	4.5
87	0.2 d	0.6	0 d	0	0.1	0.5
Aug 85	1.7 ABc	2.8	0.8 A	2.9	3.4 Bc	4.0
86	0.1 Ad	0.4	0.6 AB	1.6	1.6 Bcd	2.5
87	0 d	0	0	0	0.2 d	0.6
Sep 85	0.4 c	1.5	0.6 cd	1.3	0 c	0
86	2.0 d	3.0	2.8 d	5.5	1.2 d	1.8
87	0.2 c	0.9	0 c	0	0.1 c	0.4
Oct 85	0.2	0.8	0.3	0.7	0 c	0
86	0.4	1.2	0.2	0.4	0.3 d	0.7
87	0	0	0	0	0 c	0

1/ Site means with different upper case letters are significantly different from other sites for that month and that year. Site means with different lower case letters are significantly different from other years for that site and month.

Type 3 mycorrhizae per gram of seedling root were evenly distributed among the sites in 1987 for three of the six sampling months, and showed significant differences between various sites for the remaining three months (Table 6.2). In May, the Control site had significantly fewer Type 3 mycorrhizae per gram of seedling root than the Ground site but did not differ form the Antenna site; in August the Control and Antenna site had significantly fewer than the Ground site but did not differ from the Control site. It is difficult to explain such a combination of differences between sites for months except that for all months of 1987 the Ground site generally had higher numbers of Type 3 mycorrhizae per gram of seedling root, perhaps due to the relatively poorer soil-site quality there. The Control site only differed significantly from the other sites for two months, May and August, and for those two months the significant difference was from the Ground site, perhaps again due to soil-site quality which is relatively better on the Control site. On a site with more favorable soil conditions, lateral roots may expand faster, producing higher mycorrhizal numbers at a greater distance from the root crown of the seedling, and thus beyond retrieval by our sampling method.

Comparisons between years for any one site and month show that 1985 was less like the following two years than 1986 or 1987 were from each other. In 1985, there were generally more Type 3 mycorrhizae per gram of seedling root than in 1986 and 1987, with significantly higher numbers occurring on all three sites from August through October. Only twice did 1986 and 1987 differ significantly between sites by month: in May on the Control site and in October on the Ground site. Within the overall design of the study, for all years and months and sites taken together, there are no significant differences between sites, between months by site, or between years by site for Type 3 mycorrhizae per gram of seedling root. Differences only occur between years, due primarily to 1985. The differences between 1985 and the following two years may be due to continued adjustment to the planting site by the seedlings in 1985, their second growing season in the field. More of the root system and mycorrhizae were likely to still be concentrated in the immediate vicinity of the seedling root crown on newly outplanted seedlings. Few differences between 1986 and 1987 occurred, indicating that sampling methods between years are comparable and that seedlings are reaching an equilibrium of establishment.

Type 5 mycorrhizae have generally increased in frequency of occurrence on the red pine seedlings root systems on all three sites since the start of the study. Very few differences occurred between sites for any month and year (Table 6.3). In 1985, only in May was there a significant difference between sites; the Antenna site had higher numbers of Type 5 mycorrhizae per gram of seedling root than did the Ground or Control sites. In 1986, there were no significant differences between sites for any given month. In 1987, three months had significant differences between sites. In June,

Table 6.2 **Mean and standard deviation of Type 3 mycorrhizae per gram of seedling root (o.d.w.) for red pine seedlings, 1985-1987.**

	Ground		Antenna		Control	
Mo/Yr	$\bar{X}$1/	SD	$\bar{X}$	SD	$\bar{X}$	SD
May 85	1052 c	680	1250	776	1030 c	652
86	1719 Ad	823	1611 A	892	2587 Bd	1439
87	1386 Acd	1002	1119 AB	742	737 Bc	617
Jun 85	1284	700	880 c	405	846 c	742
86	1552	658	1500 d	578	1515 d	963
87	1830	1149	1755 d	1253	1079 cd	869
Jul 85	1326 A	966	1563 AB	1535	2403 Bc	1342
86	1763	922	1827	690	1657 d	684
87	1479	529	1101	522	1179 d	557
Aug 85	2527 c	985	2410 c	2139	2114 c	1147
86	1354 d	413	1247 d	663	1079 d	623
87	1372 Ad	339	916 Bd	305	963 Bd	522
Sep 85	3419 c	1453	3388 c	1533	2836 c	802
86	1066 d	752	875 d	386	679 d	439
87	493 d	272	719 d	491	880 d	678
Oct 85	2006 c	1144	2300 c	776	2665 c	1146
86	248 Ad	267	312 ABd	148	407 Bd	173
87	1066 Ae	509	678 Bd	381	913 ABd	356

1/ Site means with different upper case letters are significantly different from other sites for that month and that year. Site means with different lower case letters are significantly different from other years for that site and month.

Table 6.3. **Mean and standard deviation of Type 5 mycorrhizae per gram of seedling root (o.d.w.) for red pine seedlings, 1985-1987.**

	Ground		Antenna		Control	
Mo/Yr	$\bar{X}$1/	SD	$\bar{X}$	SD	$\bar{X}$	SD
May 85	3 Ac	12	62 B	132	2 Ac	9
86	57	117	126	149	168 d	187
87	158 d	103	144	116	183 d	168
Jun 85	10 c	21	9 c	13	6 c	6
86	188 d	192	160 d	89	221 cd	219
87	274 ABd	192	159 Bd	159	421 Ad	506
Jul 85	19 c	23	26 c	37	8 c	11
86	135 d	153	200 d	209	170 c	233
87	145 Ad	118	203 Ad	157	425 Bd	456
Aug 85	29 c	45	20 c	32	49 c	76
86	217 d	185	262 d	172	176	137
87	136 d	106	222 d	294	204 d	251
Sep 85	45 c	68	35 c	58	26 c	29
86	250 d	204	281 d	283	203 d	21
87	90 Ac	69	74 Ac	80	195 Bd	172
Oct 85	29 c	31	34 c	36	67	82
86	130 d	130	89 cd	57	93	69
87	150 d	104	146 d	159	141	137

1/ Site means with different upper case letters are significantly different from other sites for that month and that year. Site means with different lower case letters are significantly different from other years for that site and month.

numbers at the Control site were higher than at the Antenna site but did not differ from the Ground site. In July and August, the Control site had higher numbers than both of the other sites. It appears that seedlings on the Control site are developing more Type 5 mycorrhizae sooner than are seedlings on the Antenna or Ground sites. The responsible fungus (Cenococcum) is evidently a later successional stage species and favored on the Control site which has relatively better soil-site quality.

Comparisons from year to year for any site and month show that significant differences are attributed to 1985 more than to any other year at any site and for any month, 1985 having had significantly fewer Type 5 mycorrhizae per gram of seedling root for all but two of the months and sites considered. 1986 and 1987 differed significantly only in May and September for the Ground site, in September for the Antenna site and in July for the Control site. Within the overall design of the study, examining sites and months and years collectively, there are no significant differences between sites, months by site or years by site. The significant difference between years, attributable to 1985, is probably due to seedlings still becoming established under field conditions, with root systems slowly being colonized by indigenous fungi and attaining an equilibrium point sometime in the future. Evidence for this is provided by the relatively few significant differences found between 1986 and 1987 for any site and month for Type 5 mycorrhizae per gram of seedling root.

Type 6 mycorrhizae are the least common type encountered on red pine seedling root systems on all of the study sites. In 1985, Type 6 mycorrhizae were recorded only in July and August on the Control site. In 1986, no seedlings were found with Type 6 mycorrhizae. In 1987 the occurrence of Type 6 mycorrhizae was still infrequent and sporadic (Table 6.4), but they were found often enough on all sites (but not all months) to make comparisons between sites for the year. Within the overall design of the study (omitting the year factor in this case), considering all months taken together, there were significant differences between sites for some months of 1987 for Type 6 mycorrhizae per gram of seedling root. Type 6 mycorrhizae were equally distributed across the three study sites except for two months of the growing season. In August and September, the Control site seedlings had significantly higher numbers of Type 6 mycorrhizae per gram of seedling root. For the last four months of 1987, the Control site had more Type 6 mycorrhizae per gram of seedling root than either of the treatment sites. This may reflect the relatively better soil-site characteristics of the Control site. Seedlings planted at the Control site may be colonized sooner by some of the later successional stage fungi, including those responsible for Type 6 mycorrhizae. This same trend was seen with Type 5 mycorrhizae on the Control site. It is expected that seedlings on all sites will continue to be colonized by Type 6-forming mycorrhizal fungi, and that the abundance of

Table 6.4. **Mean and standard deviation of Type 6 mycorrhizae per gram of seedling root (o.d.w.) for red pine seedlings, 1987.**

	Ground		Antenna		Control	
Month	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
May	0	0	0	0	0	0
Jun	8	30	3	11	1	4
Jul	0	0	2	4	3	6
Aug	3 ab	5	0 a	0	11 b	20
Sep	0 a	0	0 a	0	13 b	22
Oct	5	9	4	8	9	31

ab site means with different letters are significantly different from other site means for that month.

Type 6 mycorrhizae will continue to increase as time progresses.

Many of the patterns seen regarding Type 3 mycorrhizae are also reflected in total mycorrhizae per gram of seedling root (Table 6.5). This is because Type 3 mycorrhizae constitute the majority of mycorrhizae occurring on the seedlings on the study sites. Significant differences seldom occur between sites in total mycorrhizae per gram of seedling root for any given month within years. In 1985, only in July was there a significant difference recorded; the Control site had higher numbers than the Ground site but was not significantly different from the Antenna site. In 1986, only in May was there a significant difference recorded; the Control site had higher numbers than both other sites. In 1987, three months had significant differences between sites. In August, the Control site had fewer total mycorrhizae per gram of seedling root than the Ground site but did not differ from the Antenna site. In September, the Control site had higher numbers than the Ground site but again did not differ from the Antenna site. In October, the Ground site had higher numbers than the Antenna site but neither differed from the Control site. There does not seem to be a regular pattern to the few significant differences which occurred between sites for any month and year, except that for only one month between 1985 to 1987 (May, 1986) did the Control site differ significantly from both treatment sites at the same time.

Once again, as with Type 3 and Type 5 mycorrhizae, comparisons of total mycorrhizae per gram of seedling root between years for any site and month indicate that 1985 differed significantly from 1986 and 1987 far more often than 1986 or 1987 differed from each other. In 1985, there are generally lower numbers of total mycorrhizae early in the season. This probably reflects seedling establishment and a subsequent proliferation of mycorrhizae within close proximity of seedling root crowns, which were easily retrieved by the sampling method employed. As seedlings become established, a higher proportion of mycorrhizae are presumed to develop at greater distance from the seedling, reflected in the data of 1986 and 1987 as lower numbers of total mycorrhizae per gram of seedling root for those years and also as the season progresses.

Within the overall design of the study, considering, months and years collectively from 1985 to 1987, there is no significant difference between sites or years by site. Differences between years alone are probably due to seedling establishment, as discussed above, and especially to the single year 1985, when seedlings had significantly lower numbers of total mycorrhizae per gram of seedling root early in the season and significantly higher numbers later in the season. Fewer differences between 1986 and 1987 indicates that seedlings are adapting to field conditions and an equilibrium is being attained.

Table 6.5. Mean and standard deviation of total mycorrhizae per gram of seedling root (o.d.w.) for red pine seedlings, 1985-1987.

	Ground		Antenna		Control	
Mo/Yr	$\bar{X}$1/	SD	$\bar{X}$	SD	$\bar{X}$	SD
May 85	1055 c	676	1313	756	1033 c	650
86	1775 Ad	804	1737 A	915	2755 bd	1433
87	1544 cd	1023	1263	745	920 c	588
Jun 85	1294 c	697	888 c	409	852 c	742
86	1740 cd	644	1660 d	597	1736 d	1002
87	2104 d	1226	1914 d	1274	1500 cd	1179
Jul 85	1351 A	976	1519 AB	1553	2411 bc	1342
86	1898	900	2027	739	1827 cd	745
87	1624	573	1306	548	1608 d	779
Aug 85	2557 c	989	2429 c	2145	2163 c	1175
86	1571 d	432	1510 cd	272	1256 d	690
87	1511 Ad	394	1188 ABd	629	915 Bd	400
Sep 85	3464 c	1482	3423 c	1552	2861 c	800
86	1316 d	808	1156 d	604	882 d	446
87	583 Ad	291	793 ABd	482	1088 Bd	813
Oct 85	2035 c	1151	2334 c	786	2732 c	1166
86	379 d	311	401 d	163	500 d	160
87	1220 Ae	556	828 Be	514	1062 ABe	336

1/ Site means with different upper case letters are significantly different from other sites for that month and that year. Site means with different lower case letters are significantly different from other years for that site and month.

Covariate Analysis

The object of covariate analysis is to explain some of the differences in plantation seedling establishment between sites and years by taking into account the variation in ambient weather and soil conditions among sites and years. Ambient variables were related to mycorrhizal development of seedling root systems, as a sum or average of each ambient variable for the 30 day period prior to root sampling date (a complete list of the ambient variables is in Table 6.6).

Correlations were performed to find which of the ambient variables were most likely to serve as covariates to explain observed variation in mycorrhizae per gram of seedling root among sites and years. Correlation coefficients (r) for mycorrhizae per gram of seedling root with the ambient variables are shown in Table 6.6.

Comparing years, it can be seen that there are many situations when the same covariate produces a positive correlation in one year and a negative correlation in another. This occurs more often when 1985 coefficients are compared to other years than when 1986 and 1987 coefficients are compared to each other. 1985 data also shows more significant differences in mycorrhizae per gram of seedling root compared to other years. Correlation coefficients for the three years taken together are generally low when compared to coefficients calculated for just the two years 1986 and 1987 taken together. Therefore the indications are that 1986 and 1987 seedlings, being older, more established and better adapted to field sites, reflect ambient variables more accurately than 1985 seedlings. The most highly correlated ambient variables for 1986 and 1987 taken together (air temperature degree days running total, $r=-.39$; soil temperature 5 cm degree days running total, $r=-.39$; soil temperature 10 cm degree days running total, $r=-.40$; precipitation weekly running total, $r=-.41$; number of precipitation events greater than .01 cm running total, $r=-.44$; number of precipitation events greater than .10 cm running total, $r=-.42$) are likely to be the covariates which explain site and year differences in mycorrhizae per gram of seedling root most adequately.

Analysis of variance (ANOVA) is performed with three years of data to detect differences between the various factors, and their interactions, on the seedling parameter of mycorrhizae per gram of seedling root. Table 6.7, (top row, "no covariate") shows that no significant differences ($p=0.05$) occur among sites, months by site, years by site or years by month by site. Significant differences for month, year and year by month were found ($p<0.05$). These factors are time dependent and are probably related to seasonal and/or yearly growth fluctuation and establishment of newly planted seedlings as discussed above.

To test whether the addition of a covariate explained significant amounts of variation in the response variable an analysis of covariance (ANCOVA) was performed on the three years of collected data. Table 6.7 lists P values after

Table 6.6. **Pearson correlation coefficients (r) calculated for total mycorrhizae per gram of seedling root with ambient parameters (three years data).**

Ambient Parameter	1985	1986	1987	1986-87	1985-87
AT1/	.0607	.3923*	.2201*	.2811*	.2931*
ST5	.0185	.3519*	.2140*	.2757*	.2834*
SM5	-.1348	-.1549	.2172*	-.0112	-.1430*
ST10	.0371	.3233*	.2001*	.2532*	.2837*
SM10	-.0841	-.1518	.1587	-.0384	-.1737*
ATDD	.0715	.3751*	.2219*	.2728*	.1038
ATDDRT	.5198*	-.5189*	-.2625*	-.3934*	-.0446
ATDMN	-.1195	.2623*	.1911*	.2121*	.2626*
ATDMX	.1670	.4771*	.2522*	.3510*	.3097*
ST5DD	.0250	.3516*	.2137*	.2753*	.0994
ST5DDRT	.5150*	-.5259*	-.2539*	-.3927*	-.0116
ST10DD	.0431	.3252*	.1992*	-.2534*	.0966
ST10DDRT	.5151*	-.5278*	-.2573*	-.3978*	-.0172
PRWTOT	.1907*	-.5407*	.1650	-.1930*	.0279
PR.01	.0264	-.3982*	.2373*	-.2007*	-.0846
PR.10	.2249*	-.3951*	.1660	-.1634*	.0041
PRDMX	.1055	-.5013*	.1656	-.1900*	.0299
PRWRT	.4439*	-.5800*	-.2579*	-.4070*	.0735
PR.01RT	.45128	-.5716*	-.2684	-.4379*	.0163
PR.10RT	.4715*	-.5580*	-.2343*	-.4188*	.0550

*indicates significant correlation (p=0.001)

1/AT = air temperature
ST5 = soil temperature at 5 cm
SM5 = soil moisture at 5 cm
ST10 = soil temperature at 10 cm
SM10 = soil moisture at 10 cm
ATDD = air temperature (degree days)
ATDDRT = air temperature (degree days running total)
ATDMN = air temperature (daily minimum)
ATDMX = air temperature (daily maximum)
ST5DD = soil temperature at 5 cm (degree days)
ST5DDRT = soil temperature at 5 cm (degree days running total)
ST10DD = soil temperature at 10 cm (degree days)
ST10DDRT = soil temperature at 10 cm (degree days running total)
PRWTOT = precipitation (weekly total)
PR.01 = number of days precipitation events greater than 0.01 cm
PR.10 = number of days precipitation events greater than 0.10 cm
PRDMX = precipitation (daily maximum)
PRWRT = precipitation (weekly running total)
PR.01RT = days precipitation greater than 0.01 cm (running total)
PR.10RT = days precipitation greater than 0.10 cm (running total)

Table 6.7. Comparison of P values (significance of F) for mycorrhizae per gram of seedling root data (1985, 1986, 1987, all months, all sites) after multiple analysis of covariance (ANCOVA) using different ambient parameters individually as covariates.

COVARIATE	SITE	MONTH	MOxSITE	YEAR	YEARxSITE	YEARxMO	YRxMOxSITE
No Covariate	.633	.003	.244	.000	.545	.000	.068
AT1/	.642	.152	.289	.046	.498	.000	.082
ST5	.596	.258	.241	.146	.573	.000	.084
SM5	.205	.164	.221	.004	.592	.000	.230
ST10	.507	.195	.241	.116	.538	.000	.066
SM10	.037	.212	.281	.031	.587	.000	.190
ATDD	.689	.186	.297	.408	.646	.000	.082
ATDDRT	.546	.003	.278	.021	.539	.000	.105
ATDMN	.790	.120	.290	.068	.505	.000	.083
ATDMX	.732	.538	.646	.012	.152	.000	.074
ST5DD	.584	.203	.282	.049	.571	.000	.077
ST5DDRT	.576	.003	.273	.000	.532	.000	.091
ST10DD	.547	.131	.271	.218	.577	.000	.085
ST10DDRT	.493	.001	.113	.005	.550	.000	.062
PRWTOT	.522	.003	.658	.000	.411	.000	.106
PR.01	.671	.002	.275	.000	.416	.000	.086
PR.10	.555	.002	.239	.000	.542	.000	.083
PRDMX	.521	.003	.402	.000	.418	.000	.095
PRWRT	.547	.003	.247	.001	.436	.000	.095
PR.01RT	.607	.003	.211	.000	.412	.000	.083
PR.10RT	.537	.002	.206	.000	.428	.000	.081

1/See Table 6.6 for key to abbreviations of ambient parameters.

analysis of covariance using each ambient parameter individually as a covariate. Changes upward of the P value decreases the difference for the factor being considered; for example, with no covariate the P value for site alone is .633; with air temperature (AT) as a covariate the P value for site becomes .642. Air temperatures explained part of the variation between sites (p=.642) in regard to mycorrhizae per gram of seedling root on those sites, though still not a significant amount. Air temperature also changes the P values for other factors tested in the analysis; month factor changes from significant .003 to not significant .152; month by site is decreased in difference from .244 to .289; year, formerly significantly different at .000, is changed to nearly not significant .046; year by site is made slightly less significantly different, being changed from .545 to .498; year by month does not change and continues to be significantly different at .000; year by month by site is rendered slightly less significantly different by changing from .068 to .082.

The pattern of change in P values for the various factors and factor interactions after analysis of covariance can be used to suggest alternative methods of calculating the ambient parameters. For example, in Table 6.7, each ambient covariate is calculated as a sum or average value for the 30 day period prior to root sampling date. This may be appropriate for air temperature data, P values for which increased across most of the factors and interactions. This may not be appropriate, however, for soil moisture data, since the P value for site was decreased considerably by this covariate. For soil moisture parameters, it may be necessary to calculate values similarly, but so as to apply a lag period in effect on the seedling to reflect slower seedling response to soil moisture conditions than to air temperature conditions. Alternative ways of calculating ambient parameters and how they relate to mycorrhizae per gram of seedling root are being explored in order to find those variables which maximally reduce the differences between factors and their interactions in the study.

Following analysis of covariance it is possible to derive adjusted means for the parameter being analyzed and the factor or interaction being tested. Table 6.8 compares observed means with adjusted means for total mycorrhizae per gram of seedling root for each site, month and year after covariate analysis, using air temperature as the ambient parameter site as covariate and with the single site factor being tested. It can be seen that air temperature moderates site means, bringing most closer together and reducing overall differences between sites. This is summarized in Table 6.9, demonstrating that the highest mean for all sites and months is adjusted downward for 1985 and 1987 and remains virtually unchanged for 1986. The lowest mean for all sites and months is adjusted upward for 1985 and 1986, while for 1987 it happens to be lowered farther still (some trade-offs cannot be avoided). The maximum difference between high and low site means for 1987 is increased by 120 mycorrhizae per gram of seedling root

Table 6.8. Observed and adjusted means for total mycorrhizae per gram of seedling root prior to and following multiple analysis of covariance (ANCOVA) using air temperature as the ambient parameter covariate (factor=site).

	Ground		Antenna		Control	
	$\bar{X}$ Observed	$\bar{X}$ Adjusted	$\bar{X}$ Observed	$\bar{X}$ Adjusted	$\bar{X}$ Observed	$\bar{X}$ Adjusted
May 85	1055	1169	1313	1447	1033	1035
86	1775	1889	1737	1871	2755	2757
87	1544	1657	1263	1397	920	922
Jun 85	1294	1153	888	972	852	1061
86	1740	1599	1660	1744	1736	1945
87	2104	1936	1914	1998	1500	1709
Jul 85	1351	1298	1589	1520	2411	2034
86	1819	1846	2027	1958	1827	1450
87	1624	1571	1306	1237	1608	1231
Aug 85	2557	2249	2429	2292	2163	2290
86	1571	1263	1510	1372	1256	1383
87	1511	1203	1188	1051	915	1042
Sep 85	3464	3253	3423	3204	2861	2823
86	1316	1105	1156	937	882	843
87	583	357	793	574	1088	1094
Oct 85	2035	2395	2334	2718	2732	2872
86	379	739	401	785	500	640
87	1220	1580	828	1212	1062	1202

Table 6.9. Summary of differences between observed and adjusted means (from Table 6.8, all sites for all months) of mycorrhizae per gram of root prior to and following multiple analysis of covariance (ANCOVA) using air temperature as the ambient parameter covariate.

Year	high $\bar{X}$ observed	high $\bar{X}$ adjusted	low $\bar{X}$ observed	low $\bar{X}$ adjusted	maximum observed difference	maximum adjusted difference
1985	3464	3255	852	972	2612	2281
1986	2755	2757	379	640	2372	2117
1987	2104	1998	583	357	1521	1641

after adjusting means. Presumably the increase occurring in 1987 is necessary to bring the sites closer together with respect to site differences among years.

Once again, as an example, adjustments in site means as moderated by covariate analysis have been demonstrated using only one ambient parameter, air temperature, calculated in one of innumerable ways, 30 day average prior to root sampling date. Other ambient parameters calculated in alternative ways warrant examination, and it is expected that differences between sites and other factors can be explained even more efficiently than the example given.

Detectable Differences

Thus far, few significant differences have been observed in sites and years (except 1985, for reasons explained above) with respect to mycorrhizae per gram of seedling root when individual one-way analysis of variance are performed. Multiple analysis of variance on the three years of data from all sites and sampling dates demonstrates no significant difference between sites or years by site, causing us to accept the null hypothesis that there is no difference between ELF study sites in the abundance of mycorrhizae on plantation red pine seedlings. The use of ambient parameter variables as covariates in the overall analysis reduces the difference between sites and years by sites. Refinements of the analysis by finding more appropriate temporal relationships between the ambient data and seedling mycorrhizae can be expected to explain differences among the sites before ELF fields are present.

Table 6.10 illustrates calculated detection limits necessary to recognize a significant difference in the total mycorrhizae per gram of seedling root between sites and between years by site for each year of the study thus far. A change by the percentile indicated would suggest a shift in mycorrhizal numbers on red pine seedling root systems which might possibly be attributable to ELF effects. It can be seen in Table 6.10 that for a detection of difference between sites there is less of a change required than for a detection of difference between years. The responsible factor here is the yearly progressional growth of seedlings, especially due to establishment in early years of the study. Detection limits between years should improve as seedlings equilibriate to field conditions and reach a more uniform rate of growth which is more characteristic of trees as compared to seedlings.

It can also be seen in Table 6.10 that even though an ambient covariate (air temperature or air temperature daily maximum) helped to raise the significance level among sites and years by site, it did not increase the sensitivity for detecting a difference in these factors to any great degree, and sometimes the covariate even caused a decrease in the detectable difference. This is primarily due to the procedure involved in calculating detection limits, since each time a

Table 6.10. Detectable differences (% DD) between sites within year and year by site based on mean squared error term for the factor tested; values are percent of total mycorrhizae per gram of seedling root (o.d.w.) of grand means for each year. Comparison is also shown between analysis conducted on data alone and with covariates of air temperature (AT) and air temperature daily maximum (ATDMX).

		% DD for Sites			% DD for Year by Site		
YEAR	GRAND MEAN	NO COVARIATE	+ AT	+ ATDMX	NO COVARIATE	+ AT	+ ATDMX
1985	1988 a	9	10	10	15	15	13
1986	1451 b	12	13	13	21	20	18
1987	1279 b	14	15	15	24	23	20
3 Years Combined	1573	11	12	12	19	19	17

ab yearly grand means with different letters are significantly different at the $p=0.05$ level.

covariate is used in the analysis a degree of freedom is lost in the error mean squares term which is used to calculate detectable difference. In the end, even though part of the difference between factors tested is explained by a covariate, the result of adding a covariate can be to increase detection limits. This is seen when the covariates given as an example are applied to the detectable difference between sites; detectable difference between years is rendered more sensitive by the covariates used. It can be said, with respect to mycorrhizae per gram of seedling root, that with or without covariates incorporated in the analysis, a difference of approximately 10 to 15 percent would be necessary to recognize a difference among sites as significant, and a difference of approximately 15 to 25 percent would be necessary to identify a significant difference among years by sites. Detectable differences such as these among sites and years, the most important factors of interest in our study, supports the proposal that the mycorrhizal symbiosis between tree roots and fungi can indeed be used as a sensitive indicator of subtle environmental perturbation.

Element 7. LITTER PRODUCTION

Litter fall and decomposition is important in the transfer of nutrients and energy within a vegetative community. The sensitivity of foliage production to both tree physiological changes and non-independent external climatic conditions make it a good indicator of possible ELF field effects on trees. Since litter samples can be gathered at frequent intervals, they provide an estimate of change in canopy production. Additionally, leaf samples taken during the growing season for nutrient analysis and weight determination would monitor nutrient accumulation and subsequent nutrient translocation from the foliage to the branches prior to leaf fall. This physiological process is also sensitive to environmental stress and would be a potential indicator of ELF field effects.

The objective of this element is to obtain information on total litter weight and nutrient content, and foliar nutrient levels of northern red oak during the growing season on the antenna and control plots prior to the operation of the ELF communication system. Two overall null hypotheses will be tested in this study.

H_O: There is no difference in the total weight of litter fall (leaves, wood, and miscellaneous) before and after the ELF antenna becomes operational.

H_O: There is no difference in the foliar nutrient concentrations of northern red oak trees before and after the ELF antenna becomes operational.

Each year prior to an operational antenna, a baseline relationship of the ecological systems is established through tests of the following hypotheses:

H_O: There is no difference in the total weight of litter fall between the antenna and control site within a year.

H_O: There is no difference in the foliar nutrient concentrations of northern red oak trees between the antenna and control site within a year.

The resulting ANOVA table for the analysis of litter components and northern red oak foliage concentration each year is shown below (Table 7.1).

Table 7.1. ANOVA table for the analysis of litter components and foliar nutrients

Source of Variation	df	SS	MS	F
Plot	2	SS_P	MS_P	$MS_P/MS_{E(S)}$
Site	1	SS_S	MS_S	$MS_Y/MS_{E(S)}$
Error(s)	26	$SS_{E(S)}$	$MS_{E(S)}$	
Year	# years	SS_Y	MS_Y	$MS_Y/MS_{E(Y)}$
Site x year	(1)(#yrs-1)	SS_{SXY}	MS_{SXY}	$MS_{SXY}/MS_{E(Y)}$

Sampling and Data Collection

Five $1m^2$ meter litter traps are being used to monitor tree litter production on each permanent measuring plot at the antenna and the control sites. Litter was collected monthly during the summer and weekly after the onset of leaf fall in early September. Crown nutrient concentrations and translocation in northern red oak leaves are being examined by collecting foliage samples at both the antenna and control site during the summer months. An analysis of stem diameter data indicated that sampling trees of 15 cm, 21 cm and 32 cm would adequately represent the distribution of red oak on each site. Three trees of each diameter were located off of the permanent measurement plots at each site to minimize disturbance. Leaf samples were obtained from near the top of the crown using a 12 gauge shotgun with a full choke.

All litter and foliage samples were dried at 60°C in a forced draft oven. The litter was separated into leaves, wood, and miscellaneous categories and weighed. Leaf litter from a 0.25 m^2 compartment in each trap was separated by tree species. A representative subsample of ten leaves was taken from each foliage collection and weighed. All samples were ground to pass a 40 mesh sieve for subsequent N, P, K Ca and Mg analysis.

Progress

In 1987, the major litter fall in the ELF study area started between September 24 and October 1 and was completed by October 22 on both the antenna and control sites (Figure 7.1). This litter fall period was similar to 1986 but occurred earlier than either 1984 or 1985 (Figure 7.2). Periodic litter fall amounts varied considerably between the antenna site and the control site at all collection times in the fall. These differences in weekly leaf fall were related to the variable tree species composition at each site. The leaf litter at the antenna site has a much higher proportion of red maple and big tooth aspen than the control site (Table 7.2). Oak leaves remained on the trees longer than the maple or aspen, and accounted for much of the litter fall variations between locations.

An analysis of variance (ANOVA) showed no significant differences between litter weights on the antenna and control for any of the three litter components. When litter weights on both sites were combined, a significantly greater leaf and miscellaneous litter fall occurred in 1986 than in the other years (Table 7.3). The occurrence of a significant difference in litter fall among years would complicate the determination of possible ELF field effects after the antenna becomes fully operational. Consequently, attempts were made to reduce litter fall variability among years, and improve detection limits between the antenna and control site by covariate

Figure 7.1

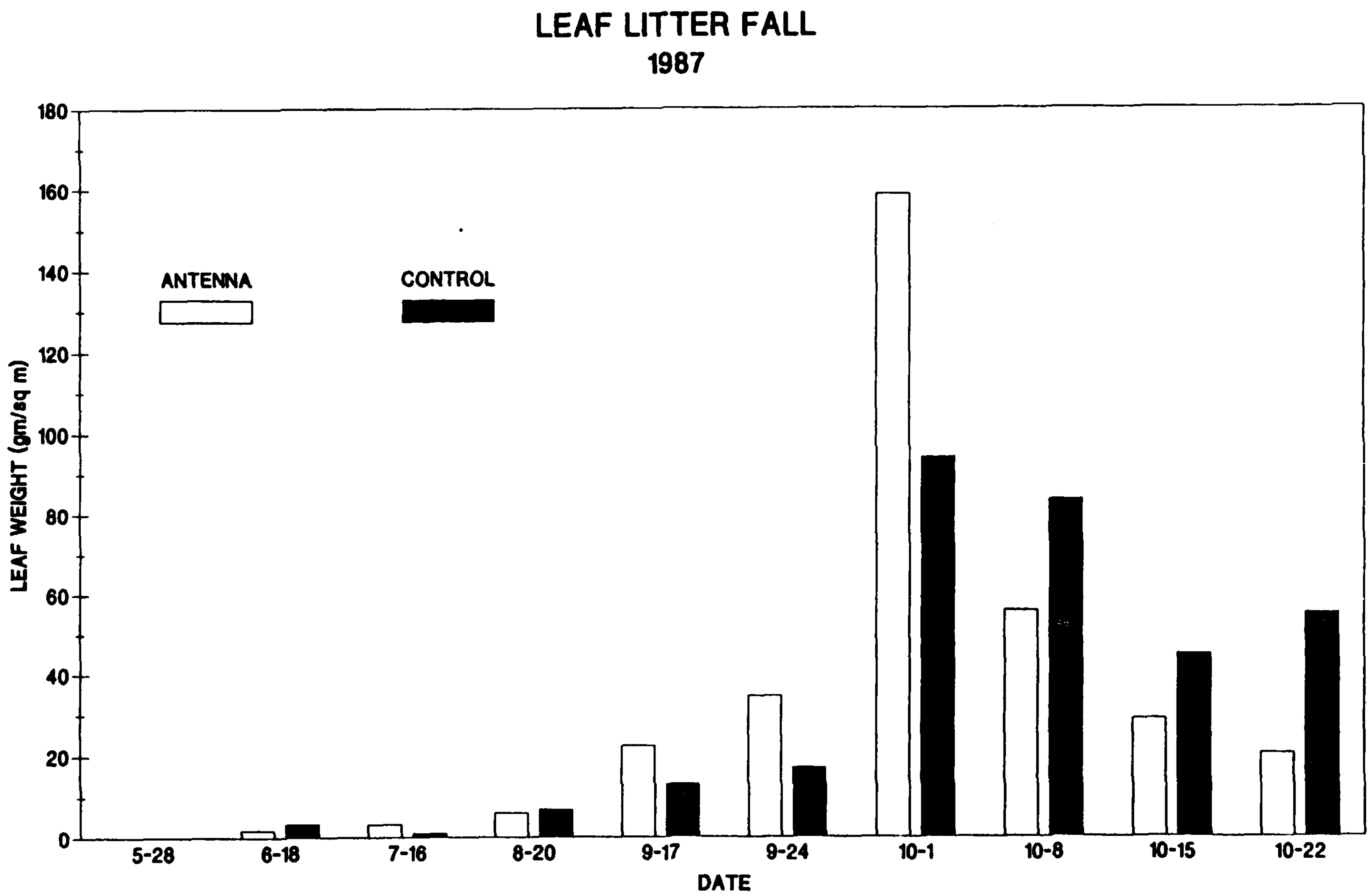
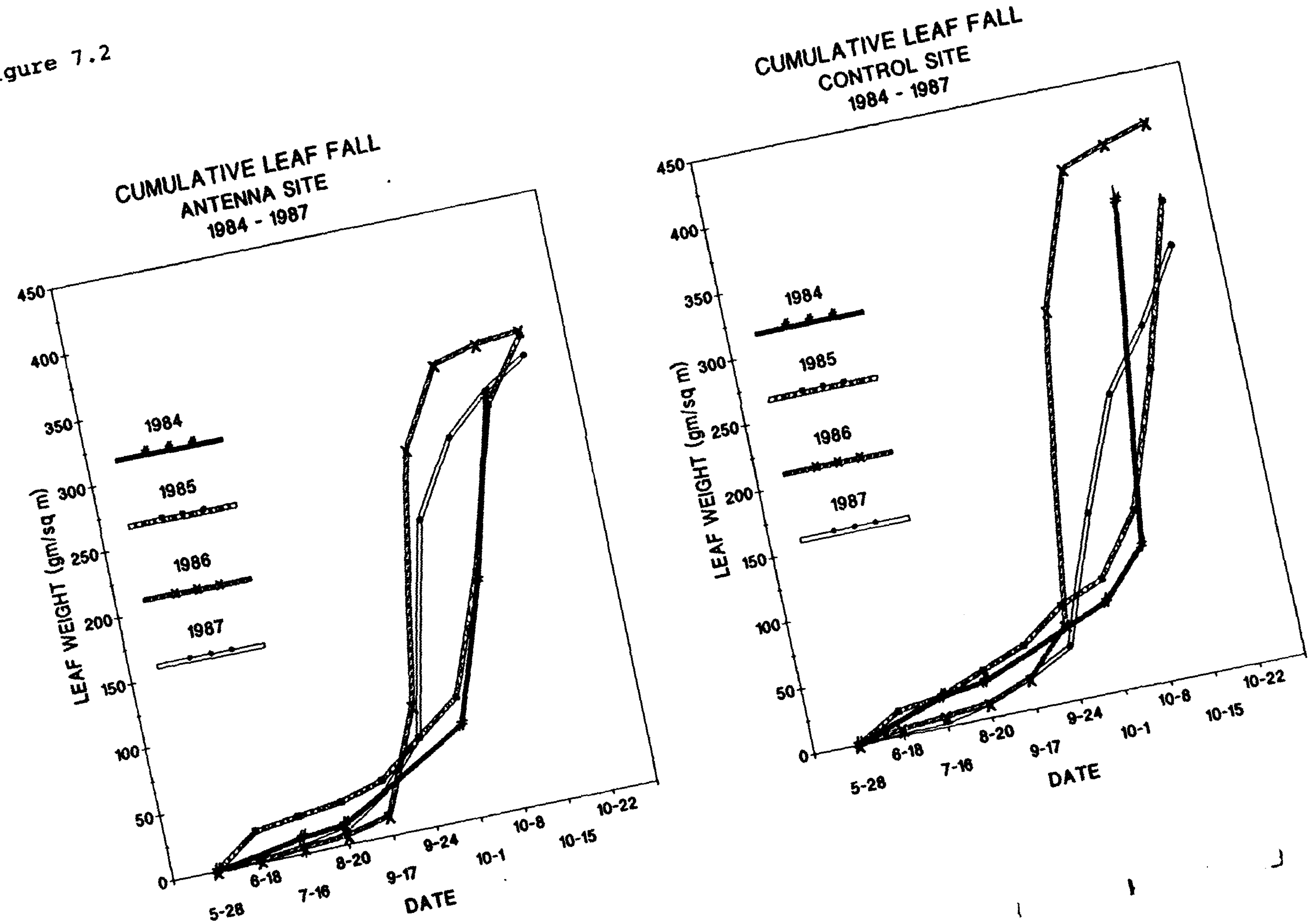

LEAF LITTER FALL
1987
ANTENNA
CONTROL
LEAF WEIGHT (gm/sq m)
0
20
40
60
80
100
120
140
160
180
5-28
6-18
7-16
8-20
9-17
9-24
10-1
10-8
10-15
10-22
DATE

Figure 7.2


CUMULATIVE LEAF FALL
ANTENNA SITE
1984 - 1987
LEAF WEIGHT (gm/sq m)
DATE
1984
1985
1986
1987
CUMULATIVE LEAF FALL
CONTROL SITE
1984 - 1987
LEAF WEIGHT (gm/sq m)
DATE
1984
1985
1986
1987

analyses using stand and environmental factors which could influence total litter production.

Table 7.2. Leaf litter fall by tree species at the antenna and control sites - 1986-1987.

	Leaf Weight (gm/m^2)			% of Total		
Tree Species	**1985**	**1986**	**1987**	**1985**	**1986**	**1987**
Antenna						
Red Maple	135	147	142	45	43	44
Red Oak	93	120	105	31	35	33
Bigtooth Aspen	45	52	46	15	15	14
Quaking Aspen	1	1	2	<1	<1	<1
Paper Birch	25	21	25	9	6	8
Red Pine	1	1	2	<1	<1	<1
Control						
Red Maple	42	55	47	14	17	16
Red Oak	227	226	208	73	69	69
Bigtooth Aspen	14	17	13	4	5	4
Quaking Aspen	11	9	8	3	3	3
Paper Birch	19	22	26	6	6	8
Red Pine	0	0	0	0	0	0

Soil and air temperature generally showed the highest correlations with litter production and gave the best results when used in the analyses of covariance (Table 7.4). The use of these covariates reduced variability in litter fall among years to a non-significant level and further lowered the P values between sites (Table 7.5).

Results of these litter studies have shown that all three litter components could be used to study the effects of ELF fields on forest stands. However, the detection limits for differences in foliage litter among years and between sites were much lower than with the wood and the miscellaneous litter fraction (Table 7.6), and so would be a more sensitive indicator of possible ELF effects. This is to be expected since both wood and miscellaneous litter fall are strongly influenced by local storm activity and resulting high winds. The lack of significance between the antenna and control sites for all three components indicated that the limited operational use of the ELF antenna in 1987 had no detectable effects on tree litter production.

Table 7.3. Total litter fall at the antenna and control sites:1984-1987.

		Antenna	Control
		-------gm/m2-------	
Leaves			
1984		307.2	357.0
1985		346.7	352.0
1986		350.9	411.7
1987		331.8	318.7
	Average	334.2	359.8
Wood			
1984		44.0	53.8
1985		55.6	63.5
1986		42.7	57.9
1987		56.8	76.1
	Average	49.8	62.8
Miscellaneous			
1984		33.8	27.5
1985		51.9	44.6
1986		32.4	28.5
1987		33.2	27.6
	Average	37.8	32.0

Collection Period: 1984 - June 20, 1984 - Oct. 24, 1984
1985 - Oct. 25, 1984 - Oct. 23, 1985
1986 - Oct. 24, 1985 - Oct. 22, 1986
1987 - Oct. 23, 1986 - Oct. 21, 1987

Table 7.4. Correlations between litter component weight and the covariates selected for inclusion in the analysis of covariance.

Covariate	Litter Component: Foliage	Wood	Miscellaneous
Soil Temperature Degree Days at 5 cm (through September)	--	.33	--
Soil Temperature Degree Days at 10 cm (through August)	--	--	.67
Air Temperature Degree Days (through September)	-.25	--	--
Air Temperature Degree Days (through July)	--	--	-.54

Table 7.5 Significance levels from the split plot analysis of covariance for litter components - 1985 to 1987

Factor	Foliage	Wood	Miscellaneous
Site	0.55	0.46	0.11
Years	0.12	0.28	0.83
Site x Years	0.21	0.79	0.66

Table 7.6. Detection limits of litter components between treatment sites and between years.*

Litter Component	Sites		Years	
	gm/m^2	%	gm/m^2	%
Foliage	60.5	17.2	40.8	11.6
Wood	35.0	59.6	21.0	35.7
Miscellaneous	12.1	33.3	13.8	37.9

*The detection limits given are for differences at p=0.05 on covariate adjusted means.

Average nutrient concentrations of the litter components for all tree species combined showed very little site differences (Table 7.7) However, when the foliage was separated and analyzed by species, site effects became evident (Table 7.8). Phosphorus and potassium levels were significantly higher on the control than on the antenna site for leaf litter of all tree species. Calcium and magnesium concentrations were only significantly higher on the control for red maple and red oak, respectively. Nitrogen values showed no differences among species between the sites. Total amount of nutrients returned to the soil on each site from litter fall reflect these differences in nutrient concentration, with greater amounts being cycled on the control for all years (Table 7.9).

Analysis of nutrient concentrations in red oak foliage showed that the limited use of the ELF antenna in 1987 had no significant effects on leaf nutrient status (Table 7.10). Potassium levels were significantly different, but this reflects the K status of the two sites prior to the onset of the ELF antenna transmissions. Foliage concentrations of K were significantly higher in oaks growing on the control as compared to the antenna site in both 1985 and 1986. No differences were evident in the nutrient concentrations of the three oak diameter classes sampled, or in the average weight of red oak leaves.

These results indicate that change in the N, Ca and Mg concentrations of leaf litter and red oak foliage would be the most suitable indicators of possible ELF field effects on tree nutrient translocation and cycling. Initial site differences in P and K status, as reflected in both foliage and litter

Table 7.7. Average nutrient concentrations of litter components on the antenna and control sites: 1984-1986.

	Antenna	Control
	------------(%)------------	
Foliage		
N	0.78[a]	0.71[a]
P	0.13[e]	0.21[f]
K	0.29[l]	0.36[l]
Ca	1.02[s]	1.09[s]
Mg	0.24[x]	0.17[x]
Wood		
N	0.60[a]	0.60[a]
P	0.06[e]	0.06[e]
K	0.12[l]	0.17[m]
Ca	1.12[s]	1.35[s]
Mg	0.06[x]	0.08[y]
Miscellaneous		
N	1.20[a]	1.21[a]
P	0.13[e]	0.16[e]
K	0.42[l]	0.31[l]
Ca	0.61[s]	1.17[s]
Mg	0.09[x]	0.09[x]

Values in rows denoted by different letters are significantly different at the p=0.05 level.

Table 7.8. Average leaf nutrient concentrations of trees on the antenna and control sites: 1985-1986.

	Antenna	Control
	(%)	
Northern Red Oak		
N	0.79[a]	0.69[a]
P	0.13[e]	0.19[f]
K	0.27[l]	0.36[m]
Ca	0.95[s]	1.01[s]
Mg	0.12[x]	0.15[y]
Paper Birch		
N	0.82[a]	0.82[a]
P	0.13[e]	0.18[f]
K	0.34[l]	0.43[l]
Ca	1.33[s]	1.19[s]
Mg	0.25[x]	0.28[x]
Big Toothed Aspen		
N	0.77[a]	0.73[a]
P	0.10[e]	0.16[f]
K	0.34[l]	0.52[m]
Ca	1.28[s]	1.53[s]
Mg	0.25[x]	0.20[x]
Red Maple		
N	0.48[a]	0.57[a]
P	0.14[e]	0.17[f]
K	0.21[l]	0.33[m]
Ca	1.00[s]	1.17[t]
Mg	0.18[x]	0.19[x]

Values in rows denoted by different letters are significantly different at the p=0.05 level.

Table 7.9. Average nutrient content of litterfall at the antenna and control sites: 1984-1986.

	Antenna			Control		
	1984	1985	1986	1984	1985	1986
	(kg/ha)					
Foliage						
N	24.2	26.4	26.4	34.0	28.1	19.9
P	3.4	4.6	4.2	4.0	10.0	4.6
K	9.0	9.9	10.1	12.5	13.6	10.5
Ca	35.0	36.0	33.1	42.6	35.7	37.2
Mg	5.8	5.7	5.5	6.9	5.6	5.8
Wood						
N	2.5	3.2	2.7	3.0	0.4	3.3
P	0.3	0.3	0.3	0.3	4.0	0.4
K	0.8	0.5	0.4	1.0	0.9	0.8
Ca	5.3	6.8	4.3	8.2	9.0	7.5
Mg	0.3	0.4	0.3	0.4	0.6	0.5
Miscellaneous						
N	6.3	7.1	3.4	3.2	5.1	3.7
P	0.5	0.8	0.3	0.3	0.9	0.3
K	1.6	2.8	1.0	1.7	1.6	0.7
Ca	2.0	3.0	2.0	1.3	5.6	3.1
Mg	0.3	0.5	0.3	0.2	0.4	0.2
Total						
N	33.0	36.7	32.5	40.2	37.2	26.9
P	4.2	5.7	4.8	4.6	11.3	5.3
K	11.4	13.2	11.5	15.2	16.1	12.0
Ca	42.3	45.8	39.4	52.1	50.3	47.8
Mg	6.4	6.6	6.1	7.5	6.6	6.5

Values in rows denoted by different letters are significantly different at the p=0.05 level.

Table 7.10. Averge nutrient concentrations of northern red oak foliage at the antenna and control sites: 1985-1987.

Nutrient	Antenna	Control
	----------(%)----------	
N	1.96[a]	1.89[a]
P	0.19[e]	0.18[e]
K	0.84[l]	0.98[m]
Ca	0.72[s]	0.74[s]
Mg	0.14[x]	0.14[x]

Values in rows denoted by different letters are significantly different at the p=0.05 level.

concentrations, would appear to limit the use of these nutrients in the study of ELF effects. However, future work will include covariate analysis with appropriate stand variables, such as soil nutrient levels, to try and reduce this site variation.

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GLOSSARY

Ambient monitoring	Recording of existing climatic factors such as temperature, wind speed, precipitation, soil temperature and moisture, and solar radiation.
Basal area	The area of the cross section of a tree at DBH.
Biomass	The amount of living matter in a unit area.
Cambial activity	The wood building process of the tree cambium which results in increased diameter.
DBH	Diameter at breast height. Average stem diameter, outside bark, at a point 4.5 feet above the ground.
Dendrometer band	A permanent device placed on a tree for measuring diameter growth.
Ectomycorrhizae	A type of mycorrhizae in which the fungi grow only intercellularly and produce and external mantle.
Endomycorrhizae	A type of mycorrhizae in which the fungi penetrate the host root cells, but do not produce a mantle.
Habitat type	Land areas potentially capable of producing similar plant communities at maturity.
Herbaceous plant	A plant that does not produce persistent woody tissue.
Litter	Dead, unincorporated leaves, twigs, seeds, plant parts, etc. on the forest floor.
Mycorrhizae	An association between plant root tissues and fungal mycelia.
NESS	National Earth Satellite Service
NOAA	National Oceanographic and Atmospheric Administration
Phenology	The science concerned with periodic biological events in plants as related to environmental variables.

Phenophase	**The timing of phenological events.**
Species diversity	**The number of different species and the amount of each in a given area.**

APPENDIX A

IIT Research Institute
10 West 35 Street, Chicago, Illinois 60616
312/567-4000

19 November 1987

Dr. Glenn Mroz
Department of Forestry
Michigan Technical University
Houghton, MI 49931

Dear Dr. Mroz:

The purpose of this letter is to provide you with documentation of the ELF electromagnetic (EM) field measurements made at your study sites on 22 and 23 September and 5 and 7 October 1987.

Study Sites.

During 1987, 32 locations (measurement points) at your Michigan study sites were examined. The location of the study sites are listed in Table 1. The position of each measurement point within a site location is shown in Figures 1 through 5. Measurement points used in 1986 were continued unaltered in 1987. Three measurement points were added in 1987 at the oak leaf, maple leaf, and pine needle sample collection areas.

Michigan Transmitting Facility (MTF) Operations - 1987

In 1987, with one exception, the MTF operated either the North-South antenna element by itself, the two East-West elements in parallel, or not at all. Virtually all operation was with antenna currents of 15 amps. The MTF antenna operated on only two days prior to 1 June 1987, totaling less than two hours. No antenna operation is planned in 1987 after 15 November. From 1 June until present the MTF has typically operated six to eight hours per day, five days per week according to a 15 minute rotational schedule, referenced to quarter hours, as follows:

First 5 minutes - both antennas off
Second 5 minutes - NS antenna only
Last 5 minutes - EW antennas only

Thus, during times of operation, each antenna had roughly a 33% duty cycle. A tabulation of 1987 MTF operating times and conditions through September is

provided in Table 2. Floppy disk files of the MTF operations database can be provided in either Lotus or dBase III formats on request. A summary of MTF operating conditions on a monthly and annual basis will be included in the 1987 EM measurement report.

EM Measurement Protocol.

The MTF continued low power operation in 1987, therefore measurements of 76 Hz fields were again possible. 60 Hz fields were also measured as in previous years.

Three types of EM fields were characterized at each measurement point: transverse (or air) electric field, longitudinal (or earth) electric field, and magnetic flux density. For each of the fields, a set of orthogonal measurements were made and reduced to a single magnitude by vector addition. EM field intensities were determined under the following conditions.

1) Measurement of the ambient 60 Hz fields with both transmitters off but connected to the antenna elements.

2) Measurement of the unmodulated 76 Hz fields from the North-South antenna with the East-West transitter off but connected to the East-West antenna.

3) Measurement of the unmodulated 76 Hz fields from the East-West antennas with the North-South transmitter off but connected to the North-South antenna.

60 Hz EM Fields.

60 Hz EM field measurement data for 1983-1987 are presented in Tables 3-5. The 1987 60 Hz measurements at the overhead antenna test site showed the same general trends in field magnitudes as were reported in 1986 as the result of 60 Hz currents coupled onto the ELF antenna elements by power lines. That is, the 60 Hz magnetic flux densities increased and the longitudinal electric fields decreased near the antenna wires in comparison to measurements made prior to antenna construction. However, the 1987 60 Hz magnetic flux densities at the overhead antenna site and both the longitudinal electric fields and magnetic flux densities at the ground test site increased significantly from 1986 levels for measurement points nearest the antenna and

ground wires. This is likely the result of several factors. For example, the antenna elements were not grounded at the transmitters during the 60 Hz measurements in 1987 as they were in 1986. Also in 1987, the two east-west antenna elements were connected in parallel. This may change the amount of 60 Hz coupling to the antenna elements. Other changes in the 60 Hz coupling may result from changes in powerline loads or changes in earth conductivity as a function of soil moisture.

In any event, the EM fields generated by the 60 Hz current on the antenna wire are localized near the antenna and do not affect the 60 Hz fields at the control sites. All 60 Hz EM field measurements at the control sites for 1987 remained consistent with previous years' measurements.

<u>76 Hz EM Fields (1987).</u>

The data taken during the 1987 annual EM measurements are included in Tables 6-8. The 76 Hz field measurements were made and are presented as vector sum magnitudes. Field magnitudes are reported for the antenna current at which the measurements were made -- 15 amperes for both the North-South and East-West antenna elements. This was the predominant operating current for the antenna elements in 1987.

The 76 Hz EM fields were still of relatively low magnitude in 1987 because of low antenna operating currents. The transverse electric field, which is easily shielded by vegetation and decays rapidly with distance from the antenna, was typically detectable only at measurement points in open areas near the antenna. The longitudinal electric field and magnetic flux density were measurable at all study sites.

<u>76 Hz EM Fields (At Operational Antenna Current.</u>

The 1987 low-power (15 ampere) EM field measurement magnitudes for each antenna element were linearly extrapolated to the planned operational antenna current of 150 amperes, and are presented in Tables 9-11. These tables also present extrapolations of the 1986 measurements, for comparison. Extrapolations were not performed when the low-power measurements were below the minimum sensitivity of the measurements instruments. The 1987 extrapolations are more accurate predictions of the EM field levels at operational antenna

current as they are based on measurement data for antenna currents 2.5 to 4 X greater than those used in 1986. The 1987 extrapolations also reflect the operational antenna configuration of the two east-west antenna elements driven in parallel, as opposed to 1986 when they were driven individually. The worst-case or maximum field levels that can occur during simultaneous operation at both antennas at any antenna phasing can be calculated as the algebraic sum of the levels from the individual antenna extrapolations. Similarly, minimums can be calculated as the algebraic difference.

The EM field extrapolations are provided to you as our best current engineering estimate of the level the field exposures that will be present at your study sites when the ELF antennas become fully operational. EM exposure ratios have not been recalculated for the 1987 data, as their primary function was that of guidelines for site selection. However, if actual field exposure levels are to be used as a co-variant for statistical analysis, you should determine whether the EM ratios between paired study site as well as EM variations or gradients across sites are consistent with your goals for the statistical power of the study. While site relocations are not feasible, some "fine tuning" of test study sites could be undertaken, if necessary, to reduce EM field variability within sites. If EM field variability is a potential problem, we may need to more closely monitor the earth electric field, which is also subject to temporal variations relating to soil moisture content. We would appreciate your comments on this subject.

1988

The 1988 MTF operating schedule has not been established and the 1988 EM measurements have not been scheduled at this time. However, we would like to know of any special engineering assistance that you may require in 1988 as early as possible. If you have any questions please contact me or Jack Zapotosky at your convenience.

Sincerely,
IIT RESEARCH INSTITUTE

James R. Gauger

James R. Gauger
Senior Engineer
(312) 567-4480

JRG/bjm
cc: Dr. J. Bruhn, Dept. of Forestry
JEZapotosky
RDCarlson/File
DPHaradem
RGDrexler

TABLE D-1. SITE NO. CROSS-REFERENCE
Upland Flora and Soil Microflora Studies

IITRI Site No.	Investigator's Site Name	Location		
		Township	Range	Section(s)
4T2	Martell's Lake (Overhead): ML	T45N	R29W	28
4T4	Martell's Lake (Buried): EP	T45N	R29W	28
4C1	Paint Pond Road Control	T41N	R32W	3
4S1	Red Maple Leaf Collection	T55N	R35W	21
4S2	Oak Leaf Collection	T41N	R32W	3
4S3	Pine Needle Collection	T54N	R34W	5

Table 2

MTF Operations Log Database
1 Jan - 30 Sept 1987
(revised 29 Oct 1987)

DATE MON	DAY	TIMEON HR	MIN	TIMEOFF HR	MIN	ANT	MOD	FREQ	CUR	PHASE	NOTES
4	28	19	15	19	40	NS	CW	76			
4	28	19	45	20	0	EW	CW	76	6		10
5	22	18	5	18	30	NS	CW	76	3		10
5	22	18	5	18	30	EW	CW	76	4		10
6	1	13	25	19	13	NS	CW	76	3		10
6	1	13	45	19	19	EW	CW	76	15		5710
6	2	13	27	19	25	NS	CW	76	15		5710
6	2	13	40	19	30	EW	CW	76	15		5710
6	3	13	30	19	10	NS	CW	76	15		5710
6	3	13	40	19	15	EW	CW	76	15		5710
6	4	13	20	19	10	NS	CW	76	15		5710
6	4	13	25	19	0	EW	CW	76	15		5710
6	5	14	5	19	25	NS	CW	76	15		5710
6	5	14	10	19	30	EW	CW	76	15		5710
6	8	13	5	19	55	NS	CW	76	15		5710
6	8	13	10	20	0	EW	CW	76	15		5710
6	9	13	5	19	25	NS	CW	76	15		5710
6	9	13	55	19	30	EW	CW	76	15		5710
6	10	13	35	19	40	NS	CW	76	15		5710
6	10	13	25	19	45	EW	CW	76	15		5710
6	11	15	5	19	20	NS	CW	76	15		5710
6	11	15	10	19	10	EW	CW	76	15		5710
6	12	13	20	19	10	NS	CW	76	15		5710
6	12	13	10	19	15	EW	CW	76	15		5710
6	15	13	20	19	10	NS	CW	76	15		5710
6	15	13	25	19	15	EW	CW	76	15		5710
6	16	13	20	20	25	NS	CW	76	15		5710
6	16	13	25	19	45	EW	CW	76	15		5710
6	16	14	35	16	5	DL	CW	76	15		56710
6	17	13	5	19	10	NS	CW	76	15		5710
6	17	12	55	19	35	EW	CW	76	15		5710
6	18	13	20	19	55	NS	CW	76	15		5710
6	18	13	12	20	0	EW	CW	76	15		5710
6	19	13	10	18	55	EW	CW	76	15		5710
6	19	13	20	18	50	NS	CW	76	15		5710
6	22	12	40	19	10	EW	CW	76	15		5710
6	22	12	50	19	20	NS	CW	76	15		5710
6	23	13	10	19	45	EW	CW	76	15		5710
6	23	13	5	19	55	NS	CW	76	15		5710
6	24	12	40	19	0	EW	CW	76	15		5710
6	24	12	35	18	55	NS	CW	76	15		5710
6	25	12	40	19	30	EW	CW	76	15		5710
6	25	12	35	19	25	NS	CW	76	15		5710
6	26	12	50	18	0	NS	CW	76	15		5710
6	26	12	55	17	45	EW	CW	76	15		5710
6	29	13	10	19	30	EW	CW	76	15		5710
6	29	13	20	19	25	NS	CW	76	15		5710
6	30	12	35	18	55	NS	CW	76	15		5710
6	30	12	40	19	0	EW	CW	76	15		5710
7	1	12	35	19	5	NS	CW	76	15		5710
7	1	12	40	19	10	EW	CW	76	15		5710
7	6	13	20	19	55	NS	CW	76	15		5710
7	6	13	25	20	0	EW	CW	76	15		5710
7	7	12	10	15	0	EW	CW	76	15		5710

Table 2 (Cont'd)

7	7	12	20	14	55	NS	CW	76	15	5710
7	8	13	10	19	30	EW	CW	76	15	5710
7	8	13	20	19	40	NS	CW	76	15	5710
7	9	12	25	19	0	EW	CW	76	15	5710
7	9	12	35	18	55	NS	CW	76	15	5710
7	7	13	50	18	55	NS	CW	76	15	5710
7	17	13	55	19	0	EW	CW	76	15	5710
7	20	13	10	18	15	EW	CW	76	15	5710
7	20	13	20	18	25	NS	CW	76	15	5710
7	21	13	50	19	10	NS	CW	76	15	5710
7	21	13	55	19	15	EW	CW	76	15	5710
7	22	12	55	19	0	EW	CW	76	15	5710
7	22	13	5	18	55	NS	CW	76	15	5710
7	23	13	5	18	55	NS	CW	76	15	5710
7	23	13	10	18	45	EW	CW	76	15	5710
7	24	13	20	19	40	NS	CW	76	15	5710
7	24	13	25	19	30	EW	CW	76	15	5710
7	27	13	5	19	40	NS	CW	76	15	5710
7	27	13	10	19	30	EW	CW	76	15	5710
7	28	12	50	19	10	NS	CW	76	15	5710
7	28	12	55	19	15	EW	CW	76	15	5710
7	29	12	25	13	45	EW	CW	76	15	5710
7	29	12	35	13	40	NS	CW	76	15	5710
7	30	12	20	19	10	NS	CW	76	15	5710
7	30	12	25	19	50	EW	CW	76	15	5710
8	3	12	50	19	25	NS	CW	76	15	5710
8	3	12	55	19	15	EW	CW	76	15	5710
8	4	12	35	19	55	NS	CW	76	15	5710
8	4	12	40	20	0	EW	CW	76	15	5710
8	5	12	50	19	55	NS	CW	76	15	5710
8	5	12	55	19	56	EW	CW	76	15	5710
8	6	13	5	19	25	NS	CW	76	15	5710
8	6	13	10	19	15	EW	CW	76	15	5710
8	7	12	40	19	15	EW	CW	76	15	5710
8	7	12	50	19	10	NS	CW	76	15	5710
8	10	12	35	19	10	NS	CW	76	15	5710
8	10	12	40	19	15	EW	CW	76	15	5710
8	11	12	35	19	40	NS	CW	76	15	5710
8	11	12	40	19	45	EW	CW	76	15	5710
8	14	17	25	19	0	EW	CW	76	15	5710
8	14	17	35	19	10	NS	CW	76	15	5710
8	17	13	25	19	15	EW	CW	76	15	5710
8	17	13	35	19	10	NS	CW	76	15	5710
8	18	12	35	18	35	NS	CW	76	15	5710
8	18	12	40	18	37	EW	CW	76	15	5710
8	19	13	20	19	10	NS	CW	76	15	5710
8	19	13	25	19	15	EW	CW	76	15	5710
8	21	13	10	17	43	EW	CW	76	15	5710
8	21	13	14	17	41	NS	CW	76	15	5710
8	24	14	25	19	7	EW	CW	76	15	5710
8	24	14	35	18	57	NS	CW	76	15	5710
8	25	13	9	18	55	NS	CW	76	15	5710
8	25	13	11	19	0	EW	CW	76	15	5710
8	26	13	56	19	13	NS	CW	76	15	5710
8	26	14	0	19	14	EW	CW	76	15	5710
8	27	12	49	17	53	NS	CW	76	15	5710

Table 2 (Cont'd)

8	27	12	50	17	54	EW	CW	76	15	5710
8	31	13	35	19	27	NS	CW	76	15	5710
8	31	13	40	19	18	EW	CW	76	15	5710
9	1	13	0	18	20	NS	CW	76	15	5710
9	1	13	8	18	21	EW	CW	76	15	5710
9	2	12	57	18	46	NS	CW	76	15	5710
9	2	12	58	18	50	EW	CW	76	15	5710
9	3	13	15	18	31	NS	CW	76	15	5710
9	3	13	17	18	22	EW	CW	76	15	5710
9	8	13	12	18	30	EW	CW	76	15	5710
9	8	13	20	18	25	NS	CW	76	15	5710
9	9	13	15	19	2	NS	CW	76	15	5710
9	9	13	16	19	3	EW	CW	76	15	5710
9	10	13	5	19	10	NS	CW	76	15	5710
9	10	13	11	19	11	EW	CW	76	15	5710
9	14	13	5	18	57	NS	CW	76	15	5710
9	14	13	10	19	0	EW	CW	76	15	5710
9	15	13	10	18	49	NS	CW	76	15	5710
9	15	13	20	18	55	EW	CW	76	15	5710
9	16	13	20	18	55	NS	CW	76	15	5710
9	16	13	25	19	0	EW	CW	76	15	5710
9	17	13	20	19	50	NS	CW	76	15	5710
9	17	13	25	19	0	EW	CW	76	15	5710
9	18	12	55	18	30	EW	CW	76	15	5710
9	18	13	5	18	40	NS	CW	76	15	5710
9	21	13	30	19	7	NS	CW	76	15	5710
9	21	13	33	19	8	EW	CW	76	15	5710
9	22	12	50	19	49	NS	CW	76	15	5710
9	22	12	55	19	54	EW	CW	76	15	5710
9	23	12	40	20	0	EW	CW	76	15	5710
9	23	12	50	19	55	NS	CW	76	15	5710
9	24	12	35	19	40	NS	CW	76	15	5710
9	24	12	40	19	53	EW	CW	76	15	5710
9	25	13	10	19	25	EW	CW	76	15	5710
9	25	13	20	19	35	NS	CW	76	15	5710
9	28	12	35	19	55	NS	CW	76	15	5710
9	28	12	40	19	51	EW	CW	76	15	5710
9	29	12	43	19	21	NS	CW	76	15	5710
9	29	12	53	19	42	EW	CW	76	15	5710
9	30	12	40	19	47	EW	CW	76	15	5710
9	30	12	50	19	50	NS	CW	76	15	5710

TABLE 3. 60 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies

Site No., Meas. Pt.	1983[a]	1984[a]	1985[a]	1986[b]	1987[c]
4C1-6	-	0.003	~	~	~
4C1-7	-	0.006	~	~	~
4C1-8	-	0.004	~	~	~
4C1-9	-	0.002	~	~	~
4C1-10	-	~	~	~	~
4C1-11	-	~	~	~	~
4C1-12	-	~	~	~	~
4C1-13	-	~	~	~	~
4T2-3	-	0.001	~	~	~
4T2-4	-	~	~	~	~
4T2-5	-	~	~	~	~
4T2-6	-	~	~	~	~
4T2-7	-	~	~	~	~
4T2-8	-	~	~	~	~
4T2-9	-	~	~	~	~
4T2-10	-	~	~	~	~
4T2-11	-	~	~	~	~
4T2-12	-	~	~	~	~
4T2-13	-	~	~	~	~
4T2-14	-	~	~	~	~
4T4-4	-	0.003	~	~	<0.001
4T4-5	-	~	~	~	0.006
4T4-6	-	~	~	~	~
4T4-7	-	~	~	~	~
4T4-8	-	~	~	~	~
4T4-9	-	~	~	~	~
4T4-10	-	~	~	~	~
4T4-11	-	~	~	~	0.010
4T4-12	-	~	-	~	0.005
4S1-1	-	-	-	-	0.013
4S2-1	-	-	-	-	~
4S3-1	-	-	-	-	<0.001

a = prior to antenna construction.
b = antenna elements grounded at transmitter (condition 2).
c = antenna elements connected to transmitter, transmitter off (condition 9).
\- = site measurement point not established.
~ = measurement expected to be <0.001 V/m based on the longitudinal electric field measurement.

TABLE 4. 60 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies

Site No., Meas. Pt.	1983[a]	1984[a]	1985[a]	1986[b]	1987[c]
4C1-6	–	0.022	0.016	0.005	0.043
4C1-7	–	0.143	0.123	0.077	0.178
4C1-8	–	0.104	0.117	0.077	0.131
4C1-9	–	0.011	0.019	0.024	0.034
4C1-10	–	–	0.090	0.068	0.118
4C1-11	–	–	0.160	0.107	0.132
4C1-12	–	–	0.104	0.101	0.075
4C1-13	–	–	0.040	0.030	0.046
4T2-3	–	0.51	0.39	0.194	0.27
4T2-4	–	–	0.27	0.24	0.30
4T2-5	–	–	0.43	0.32	0.20
4T2-6	–	–	0.66	0.46	0.192
4T2-7	–	–	0.42	0.52	0.197
4T2-8	–	–	0.47	0.190	0.22
4T2-9	–	–	0.49	0.31	0.183
4T2-10	–	–	0.44	0.32	0.155
4T2-11	–	–	0.51	0.40	0.31
4T2-12	–	–	0.47	0.38	0.24
4T2-13	–	–	0.76	0.31	0.31
4T2-14	–	–	0.61	0.29	0.35
4T4-4	–	0.72	0.42	0.185	0.56
4T4-5	–	–	0.58	0.58	4.3
4T4-6	–	–	0.22	0.16	0.61
4T4-7	–	–	0.44	0.29	0.64
4T4-8	–	–	0.42	0.193	0.40
4T4-9	–	–	0.50	0.21	0.27
4T4-10	–	–	0.42	0.22	0.29
4T4-11	–	–	0.40	0.60	2.7
4T4-12	–	–	–	0.75	3.4
4S1-1	–	–	–	–	8.5
4S2-1	–	–	–	–	0.155
4S3-1	–	–	–	–	0.65

a = prior to antenna construction.
b = antenna elements grounded at transmitter (condition 2).
c = antenna elements connected to transmitter, transmitter off (condition 9).
– = site measurement point not established.

TABLE 5. 60 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies

Site No., Meas. Pt.	1983[a]	1984[a]	1985[a]	1986[b]	1987[c]
4C1-6	-	0.003	0.003	0.003	0.002
4C1-7	-	0.003	0.002	0.001	0.003
4C1-8	-	0.003	0.003	0.002	0.003
4C1-9	-	0.003	0.003	0.002	0.001
4C1-10	-	-	0.002	0.002	0.002
4C1-11	-	-	0.002	0.002	0.002
4C1-12	-	-	0.002	0.003	0.001
4C1-13	-	-	0.002	0.003	0.001
4T2-3	-	0.002	0.001	0.001	0.003
4T2-4	-	-	0.001	0.001	0.003
4T2-5	-	-	0.001	0.007	0.017
4T2-6	-	-	0.001	0.006	0.006
4T2-7	-	-	0.001	0.004	0.004
4T2-8	-	-	0.001	0.002	0.004
4T2-9	-	-	0.001	0.003	0.003
4T2-10	-	-	0.001	0.003	0.003
4T2-11	-	-	0.001	0.004	0.005
4T2-12	-	-	0.002	0.004	0.005
4T2-13	-	-	0.001	0.005	0.008
4T2-14	-	-	0.002	0.011	0.018
4T4-4	-	0.004	0.002	0.001	0.003
4T4-5	-	-	0.002	0.006	0.010
4T4-6	-	-	0.002	0.001	0.004
4T4-7	-	-	0.001	0.001	0.004
4T4-8	-	-	0.002	0.001	0.004
4T4-9	-	-	0.002	0.001	0.002
4T4-10	-	-	0.001	0.001	0.002
4T4-11	-	-	0.002	0.002	0.012
4T4-12	-	-	-	0.002	0.010
4S1-1	-	-	-	-	0.035
4S2-1	-	-	-	-	0.003
4S3-1	-	-	-	-	0.036

a = prior to antenna construction.
b = antenna elements grounded at transmitter (condition 2).
c = antenna elements connected to transmitter, transmitter off (condition 9).
\- = site measurement point not established.

TABLE 6. 76 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
Measured (M) and Extrapolated (Ex) Data

Site No., Meas. Pt.	1986 EXPOSURES ANTENNA ELEMENT (AMPS)				1987 EXPOSURES ANTENNA ELEMENT (AMPS)	
	NS(4) M	NEW(6) M	SEW(6) M	SEW(10) Ex	NS(15) M	EW(15) M
4C1-6	-	-	-	--	-	-
4C1-7	-	-	-	--	-	-
4C1-8	-	-	-	--	-	-
4C1-9	-	-	-	--	-	-
4C1-10	-	-	-	--	-	-
4C1-11	-	-	-	--	-	-
4C1-12	-	-	-	--	-	-
4C1-13	-	-	-	--	-	-
4T2-3	¯	¯	0.004	0.007	0.002	0.014
4T2-4	¯	¯	0.005	0.008	0.001	0.014
4T2-5	0.018	¯	0.092	0.153	0.003	0.23
4T2-6	¯	¯	0.005	0.008	0.003	0.013
4T2-7	¯	¯	0.007	0.012	0.001	0.018
4T2-8	¯	¯	0.004	0.007	0.002	0.012
4T2-9	¯	¯	0.005	0.008	0.002	0.010
4T2-10	¯	¯	0.004	0.007	0.002	0.011
4T2-11	¯	¯	0.003	0.005	0.002	0.012
4T2-12	¯	¯	0.002	0.003	0.002	0.014
4T2-13	¯	¯	0.005	0.008	0.002	0.012
4T2-14	0.030	¯	0.155	0.26	0.003	0.186
4T4-4	¯	¯	0.006	0.010	0.002	0.005
4T4-5	0.033	0.008	0.20	0.33	0.019	0.27
4T4-6	0.005	¯	0.023	0.038	0.002	0.021
4T4-7	¯	¯	0.006	0.010	0.002	0.015
4T4-8	¯	¯	0.008	0.013	0.002	0.016
4T4-9	¯	¯	0.009	0.015	0.001	0.008
4T4-10	¯	¯	0.007	0.012	0.001	0.001
4T4-11	¯	0.005	0.38	0.63	0.025	0.43
4T4-12	0.055	0.005	0.43	0.72	0.017	0.30
4S1-1	-	-	-	-	-	-
4S2-1	-	-	-	-	-	-
4S3-1	-	-	-	-	-	-

NS = North-South antenna element
NEW = Northern East-West antenna element
SEW = Southern East-West antenna element
EW = both East-West antenna elements (operational configuration).
\- = site measurement point not established.
¯ = measurement expected to be <0.001 based on the longitudinal electric field measurement.

TABLE 7 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies
Measured (M) and Extrapolated (Ex) Data

Site No., Meas. Pt.	1986 EXPOSURES ANTENNA ELEMENT (AMPS) NS(4) M	NEW(6) M	SEW(6) M	SEW(10) Ex	1987 EXPOSURES ANTENNA ELEMENT (AMPS) NS(15) M	EW(15) M
4C1-6	-	-	-	--	0.002	0.002
4C1-7	-	-	-	--	0.005	0.006
4C1-8	-	-	-	--	0.004	0.004
4C1-9	<0.001	<0.001	<0.001	--	0.002	0.002
4C1-10	-	-	-	--	0.005	0.004
4C1-11	-	-	-	--	0.006	0.005
4C1-12	-	-	-	--	0.004	0.003
4C1-13	-	-	-	--	0.002	0.002
4T2-3	1.31	0.22	6.3	10.5	1.36	15.2
4T2-4	1.05	0.22	5.0	8.3	1.70	10.7
4T2-5	1.18	0.24	5.3	8.8	1.46	12.7
4T2-6	1.11	0.27	4.4	7.3	2.2	12.4
4T2-7	1.13	0.23	5.3	8.8	1.31	9.7
4T2-8	1.32	0.25	5.7	9.5	1.81	15.8
4T2-9	1.17	0.21	5.1	8.5	1.46	13.7
4T2-10	0.97	0.22	4.1	6.8	1.84	10.5
4T2-11	1.14	0.21	5.0	8.3	2.2	10.7
4T2-12	1.06	0.21	4.3	7.2	1.93	13.5
4T2-13	1.12	0.64	5.4	9.0	1.74	14.9
4T2-14	1.07	0.175	5.1	8.5	1.66	14.3
4T4-4	0.33	0.181	1.46	2.4	1.63	3.7
4T4-5	13.8	2.0	81	135	14.0	194
4T4-6	1.22	0.22	6.2	10.3	2.2	12.9
4T4-7	0.94	0.175	5.5	9.2	2.0	14.1
4T4-8	0.91	0.188	5.3	8.8	1.36	10.7
4T4-9	0.29	0.130	1.32	2.2	1.08	3.0
4T4-10	0.29	0.169	1.63	2.7	1.35	3.9
4T4-11	0.59	1.82	89	148	10.7	178
4T4-12	21	2.2	118	197	13.8	260
4S1-1	-	-	-	-	<0.001	<0.001
4S2-1	-	-	-	-	0.005	0.005
4S3-1	-	-	-	-	<0.001	<0.001

NS = North-South antenna element
NEW = Northern East-West antenna element
SEW = Southern East-West antenna element
EW = both East-West antenna elements (operational configuration).
\- = site measurement point not established.
\- = measurement expected to be <0.001 V/m based on the longitudinal electric field measurement.
-- = data cannot be extrapolated.
/ = data not taken.

TABLE 8 76 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
Measured (M) and Extrapolated (Ex) Data

Site No., Meas. Pt.	1986 EXPOSURES ANTENNA ELEMENT (AMPS) NS(4) M	NEW(6) M	SEW(6) M	SEW(10) Ex	1987 EXPOSURES ANTENNA ELEMENT (AMPS) NS(15) M	EW(15) M
4C1-6	-	-	-	--	<0.001	<0.001
4C1-7	-	-	-	--	<0.001	<0.001
4C1-8	-	-	-	--	<0.001	<0.001
4C1-9	<0.001	<0.001	<0.001	--	<0.001	<0.001
4C1-10	-	-	-	--	<0.001	<0.001
4C1-11	-	-	-	--	<0.001	<0.001
4C1-12	-	-	-	--	<0.001	<0.001
4C1-13	-	-	-	--	<0.001	<0.001
4T2-3	0.047	0.001	0.22	0.37	0.008	0.55
4T2-4	0.049	0.001	0.24	0.40	0.008	0.57
4T2-5	0.197	<0.001	1.00	1.67	0.011	2.4
4T2-6	0.058	0.001	0.44	0.73	0.006	1.16
4T2-7	0.046	0.001	0.22	0.37	0.006	0.59
4T2-8	0.045	0.001	0.22	0.37	0.006	0.59
4T2-9	0.029	0.001	0.138	0.23	0.007	0.38
4T2-10	0.033	0.001	0.149	0.25	0.006	0.39
4T2-11	0.043	0.001	0.21	0.35	0.006	0.56
4T2-12	0.047	0.001	0.23	0.38	0.006	0.61
4T2-13	0.086	<0.001	0.43	0.72	0.005	1.14
4T2-14	0.21	<0.001	1.03	1.72	0.012	2.5
4T4-4	0.019	<0.001	0.096	0.160	0.005	0.24
4T4-5	0.114	0.001	0.57	0.95	0.008	1.40
4T4-6	0.045	0.001	0.22	0.37	0.008	0.53
4T4-7	0.038	0.001	0.186	0.31	0.008	0.45
4T4-8	0.035	0.001	0.179	0.30	0.007	0.43
4T4-9	0.025	0.21	0.118	0.197	0.005	0.29
4T4-10	0.022	<0.001	0.116	0.193	0.005	0.27
4T4-11	0.161	0.001	0.80	1.33	0.011	1.89
4T4-12	0.115	0.001	0.58	0.97	0.010	1.37
4S1-1	-	-	-	-	<0.001	<0.001
4S2-1	-	-	-	-	<0.001	<0.001
4S3-1	-	-	-	-	<0.001	<0.001

NS = North-South antenna element
NEW = Northern East-West antenna element
SEW = Southern East-West antenna element
EW = both East-West antenna elements (operational configuration).
\- = site measurement point not established.
\- = measurement expected to be <0.001 based on the longitudinal electric field measurement.
-- = data cannot be extrapolated.

TABLE 9 76 Hz TRANSVERSE ELECTRIC FIELD INTENSITIES (V/m)
Upland Flora and Soil Microflora Studies
Data Extrapolated to 150 Ampere Current

Site No., Meas. Pt.	1986 EXTRAPOLATIONS NS	NEW	SEW	1987 EXTRAPOLATIONS NS	EW
4C1-6	~~	~~	~~	~~	~~
4C1-7	~~	~~	~~	~~	~~
4C1-8	~~	~~	~~	~~	~~
4C1-9	~~	~~	~~	~~	~~
4C1-10	~~	~~	~~	~~	~~
4C1-11	~~	~~	~~	~~	~~
4C1-12	~~	~~	~~	~~	~~
4C1-13	~~	~~	~~	~~	~~
4T2-3	~~	~~	0.100	0.020	0.140
4T2-4	~~	~~	0.125	0.010	0.140
4T2-5	0.68	~~	2.3	0.030	2.3
4T2-6	~~	~~	0.125	0.030	0.130
4T2-7	~~	~~	0.175	0.010	0.180
4T2-8	~~	~~	0.100	0.020	0.120
4T2-9	~~	~~	0.125	0.020	0.100
4T2-10	~~	~~	0.100	0.020	0.110
4T2-11	~~	~~	0.075	0.020	0.120
4T2-12	~~	~~	0.050	0.020	0.140
4T2-13	~~	~~	0.125	0.020	0.120
4T2-14	1.13	~~	3.9	0.030	1.86
4T4-4	~~	~~	0.150	0.020	0.050
4T4-5	1.24	0.20	5.0	0.190	2.7
4T4-6	0.188	~~	0.58	0.020	0.21
4T4-7	~~	~~	0.150	0.020	0.150
4T4-8	~~	~~	0.20	0.020	0.160
4T4-9	~~	~~	0.23	0.010	0.080
4T4-10	~~	~~	0.175	0.010	0.010
4T4-11	~~	0.125	9.5	0.25	4.3
4T4-12	2.1	0.125	10.8	0.170	3.0
4S1-1	-	-	-	~~	~~
4S2-1	-	-	-	~~	~~
4S3-1	-	-	-	~~	~~

NS = North-South antenna element
NEW = Northern East-West antenna element
SEW = Southern East-West antenna element
EW = both East-West antenna elements (operational configuration).
\- = site measurement point not established.
~~ = data cannot be extrapolated.

TABLE 10 76 Hz LONGITUDINAL ELECTRIC FIELD INTENSITIES (mV/m)
Upland Flora and Soil Microflora Studies
Data Extrapolated to 150 Ampere Current

Site No.,	1986 EXTRAPOLATIONS			1987 EXTRAPOLATIONS	
Meas. Pt.	NS	NEW	SEW	NS	EW
4C1-6	~~	~~	~~	0.020	0.020
4C1-7	~~	~~	~~	0.050	0.060
4C1-8	~~	~~	~~	0.040	0.040
4C1-9	~~	~~	~~	0.020	0.020
4C1-10	~~	~~	~~	0.050	0.040
4C1-11	~~	~~	~~	0.060	0.050
4C1-12	~~	~~	~~	0.040	0.030
4C1-13	~~	~~	~~	0.020	0.020
4T2-3	49	5.5	158	13.6	152
4T2-4	39	5.5	125	17.0	107
4T2-5	44	6.0	133	14.6	127
4T2-6	42	6.8	110	22	124
4T2-7	42	5.8	133	13.1	97
4T2-8	50	6.3	143	18.1	158
4T2-9	44	5.3	128	14.6	137
4T2-10	36	5.5	103	18.4	105
4T2-11	43	5.3	125	22	107
4T2-12	40	5.3	108	19.3	135
4T2-13	42	16.0	135	17.4	149
4T2-14	40	4.4	128	16.6	143
4T4-4	12.4	4.5	37	16.3	37
4T4-5	520	50	2000	140	194
4T4-6	46	5.5	155	22	129
4T4-7	35	4.4	138	20	141
4T4-8	34	4.7	133	13.6	107
4T4-9	10.9	3.3	33	10.8	30
4T4-10	10.9	4.2	41	13.5	39
4T4-11	22	46	2200	107	178
4T4-12	790	55	3000	138	260
4S1-1	-	-	-	~~	~~
4S2-1	-	-	-	0.050	0.050
4S3-1	-	-	-	~~	~~

NS = North-South antenna element
NEW = Northern East-West antenna element
SEW = Southern East-West antenna element
EW = both East-West antenna elements (operational configuration).
\- = site measurement point not established.
~~ = data cannot be extrapolated.

TABLE 11. 76 Hz MAGNETIC FLUX DENSITIES (mG)
Upland Flora and Soil Microflora Studies
Data Extrapolated to 150 Ampere Current

Site No., Meas. Pt.	1986 EXTRAPOLATIONS NS	NEW	SEW	1987 EXTRAPOLATIONS NS	EW
4C1-6	~~	~~	~~	~~	~~
4C1-7	~~	~~	~~	~~	~~
4C1-8	~~	~~	~~	~~	~~
4C1-9	~~	~~	~~	~~	~~
4C1-10	~~	~~	~~	~~	~~
4C1-11	~~	~~	~~	~~	~~
4C1-12	~~	~~	~~	~~	~~
4C1-13	~~	~~	~~	~~	~~
4T2-3	1.76	0.025	5.5	0.080	5.5
4T2-4	1.84	0.025	6.0	0.080	5.7
4T2-5	7.4	~~	25	0.110	24
4T2-6	2.2	0.025	11.0	0.060	11.6
4T2-7	1.73	0.025	5.5	0.060	5.9
4T2-8	1.69	0.025	5.5	0.060	5.9
4T2-9	1.09	0.025	3.5	0.070	3.8
4T2-10	1.24	0.025	3.7	0.060	3.9
4T2-11	1.61	0.025	5.3	0.060	5.6
4T2-12	1.76	0.025	5.8	0.060	6.1
4T2-13	3.2	~~	10.8	0.050	11.4
4T2-14	7.9	~~	26	0.120	25
4T4-4	0.71	~~	2.4	0.050	2.4
4T4-5	4.3	0.025	14.3	0.080	14.0
4T4-6	1.69	0.025	5.5	0.080	5.3
4T4-7	1.43	0.025	4.7	0.080	4.5
4T4-8	1.31	0.025	4.5	0.070	4.3
4T4-9	0.94	5.3	3.0	0.050	2.9
4T4-10	0.83	~~	2.9	0.050	2.7
4T4-11	6.0	0.025	20	0.110	18.9
4T4-12	4.3	0.025	14.5	0.100	13.7
4S1-1	-	-	-	~~	~~
4S2-1	-	-	-	~~	~~
4S3-1	-	-	-	~~	~~

NS = North-South antenna element
NEW = Northern East-West antenna element
SEW = Southern East-West antenna element
EW = both East-West antenna elements (operational configuration).
\- = site measurement point not established.
~~ = data cannot be extrapolated.

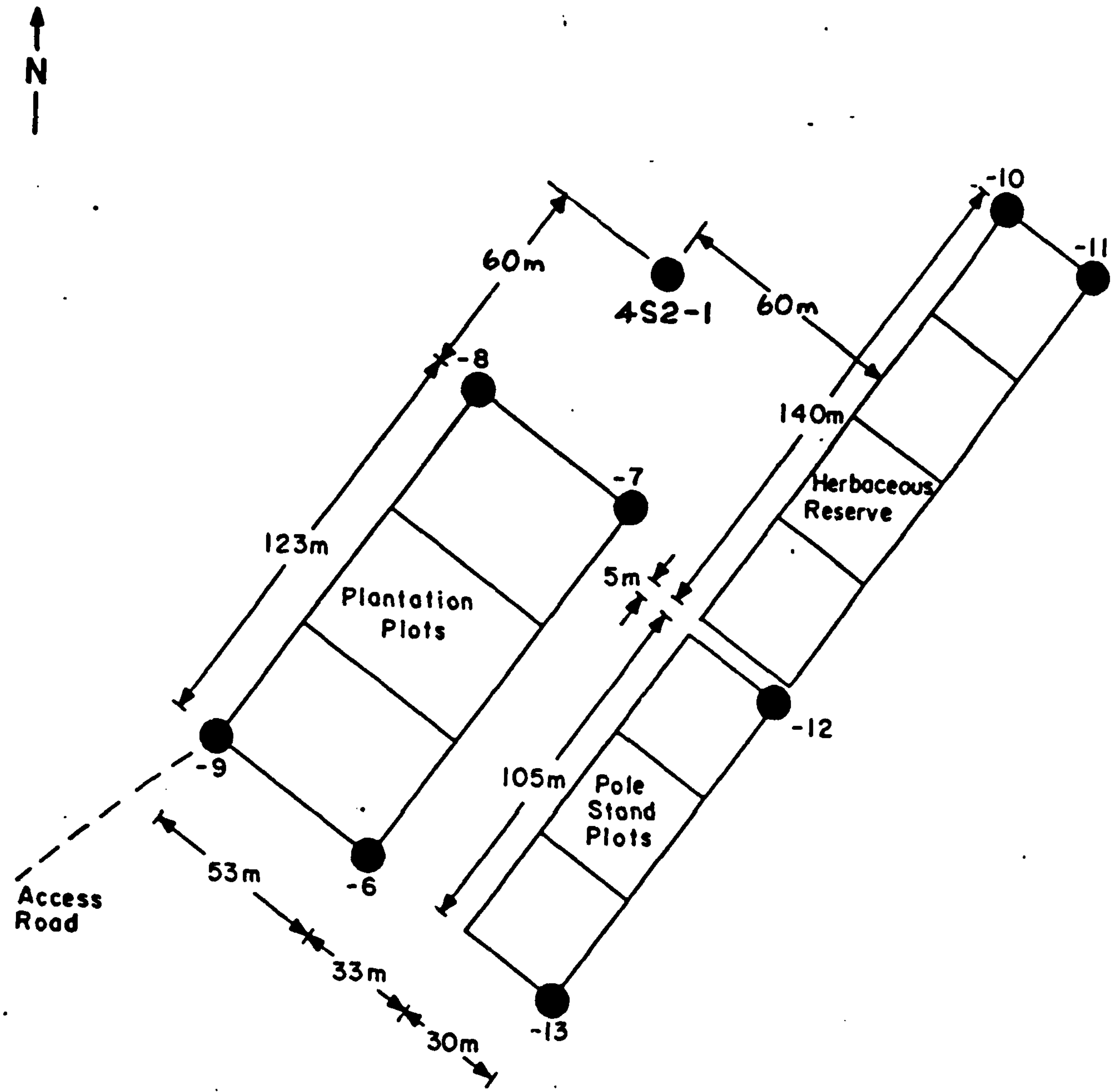


Figure 1. Measurement Points at Paint Pond Road Control, 4C1-6 through 13; and Oak Leaf Collection, 4S2-1.

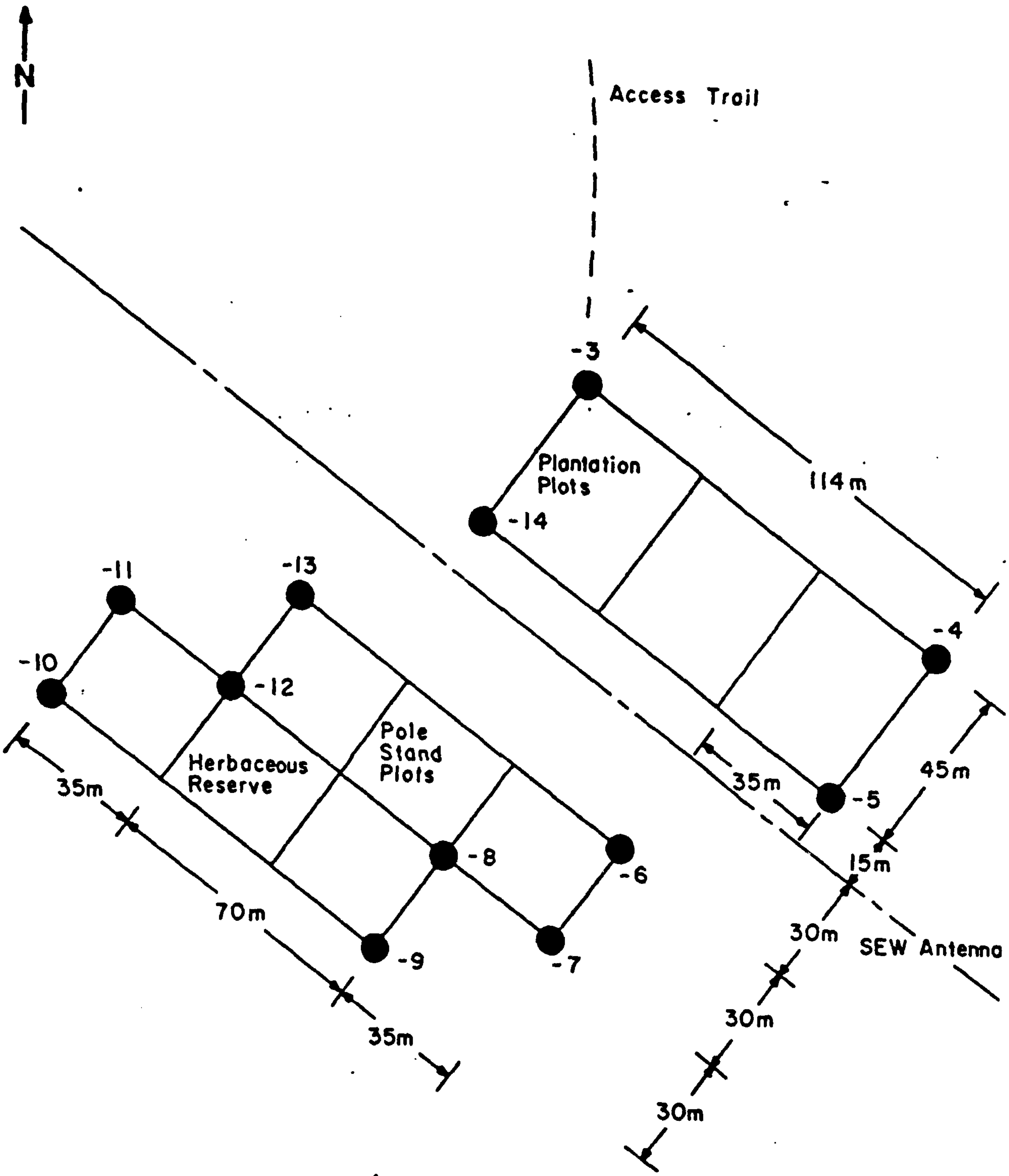


Figure 2. Measurement Points at Martell's Lake (Overhead): ML; 4T2-3 through 14.

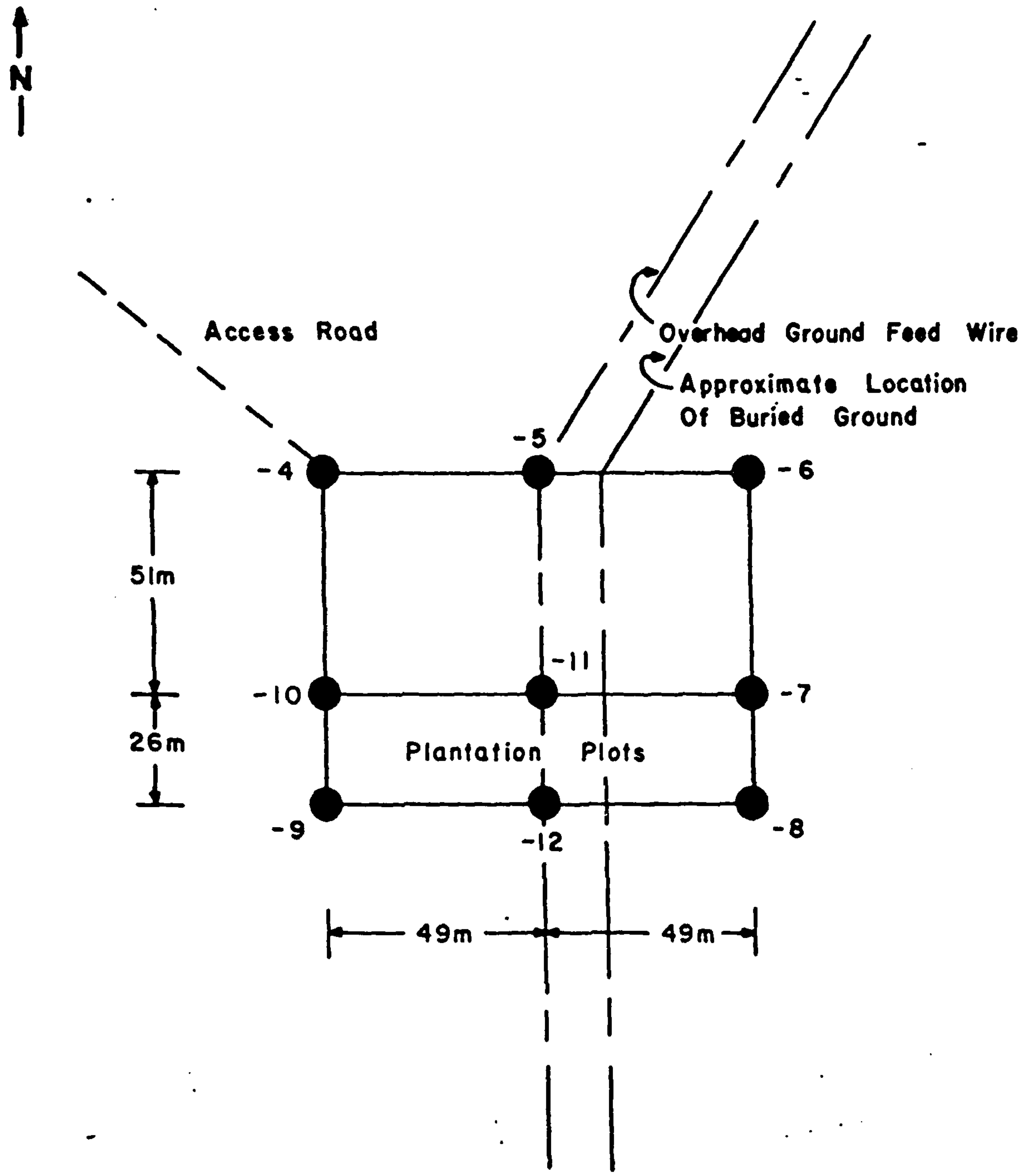


Figure 3. Measurement Points at Martell's Lake (Buried): EP; 4T4-4 through 12.

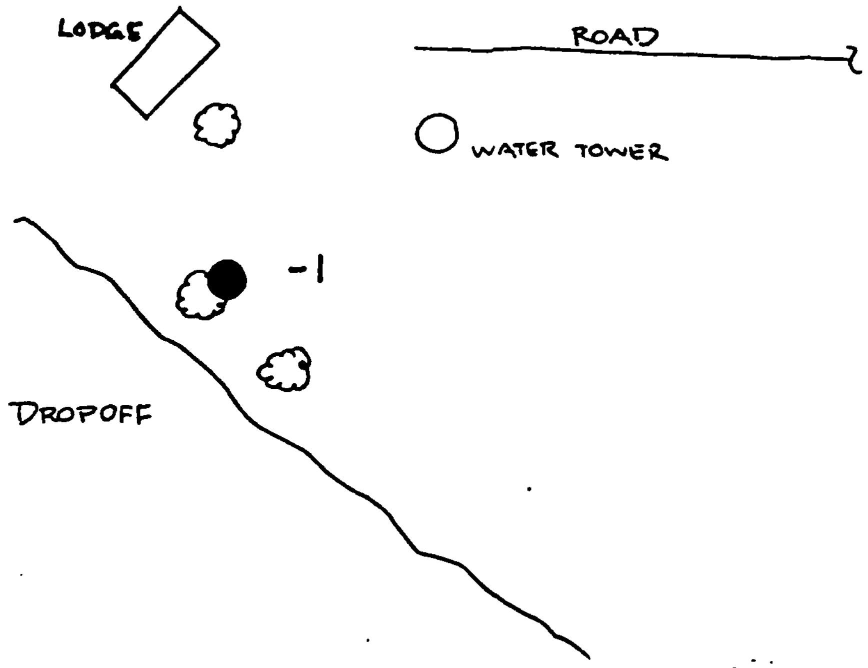


Figure 4. Measurement Point at Red Maple Collection; 4S1-1.

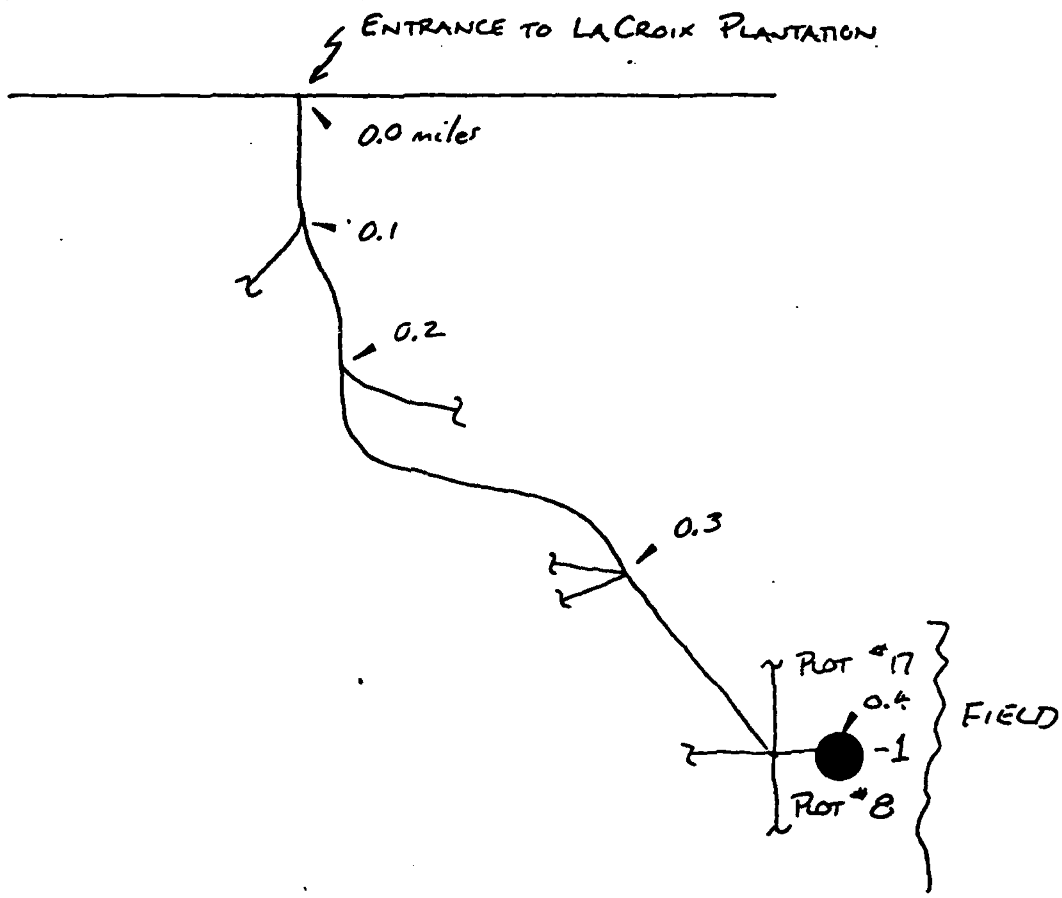


Figure 5. Measurement Point at Pine Needle Collection; 4S3-1.

APPENDIX B

Table 1. Equation 1987 to predict missing data.

1987 Missing Data Equations

Plot	Equation	Y	Standard Error	R2	Confidence Interval at X1, X2
	Control Average Daily Air Temperature				
1	$Y = .938(X)$	15.1	.198	.987	$Y \pm .39$
2	$Y = .975(X)$	15.7	.210	.986	$Y \pm .42$
3	$Y = .927(X)$	15.0	.189	.988	$Y \pm .38$
	X = average daily air temperature at Crystal Fall DNR station Y = predicted average daily air temperature plantation plots at control site				
1-3	$Y = .936(X)$	15.1	.117	.986	$Y \pm .23$
	X = average daily air temperature at Crystal Fall DNR station Y = predicted average daily air temperature on Hardwood stand at control site				
	Soil Temperature Control Plantation Plots (5 cm)				
1	$Y = 2.658(X_1)+.423(X_2)-6.417$	14.7	.213	.847	$Y \pm .42$
2	$Y = 2.545(X_1)+.395(X_2)-6.368$	13.9	.206	.849	$Y \pm .41$
3	$Y = 2.313(X_1)+.463(X_2)-4.687$	15.0	.206	.848	$Y \pm .42$
	X_1 = month of year (i.e...6,7,8) X_2 = air temperature average control plantation plots Y = plot average, daily soil temperature 5 cm on control site				
	Soil Temperature Control Hardwood Plots (5 cm)				
1	$Y = 2.184(X_1)+.525(X_2)-7.193$	13.7	.152	.904	$Y \pm .30$
2	$Y = 2.221(X_1)+.449(X_2)-7.242$	12.7	.146	.902	$Y \pm .29$
3	$Y = 2.092(X_1)+.487(X_2)-5.691$	14.1	.154	.894	$Y \pm .30$
	X_1 = month of year (i.e...6,7,8) X_2 = air temperature daily average control plantation plots Y = plot average, daily soil temperature 5 cm on control tree site				

Table 2. Equation 1987 to predict missing data.

1987 Missing Data Equations

Plot	Equation	Y	Standard Error	R2	Confidence Interval_at X1, X2
	Soil Temperature Control Plantation Plots (10 cm)				
1	$Y = 2.776(X_1)+.343(X2)-6.239$	15.2	.184	.859	Y ± .37
2	$Y = 2.702(X_1)+.341(X2)-6.483$	14.7	.187	.856	Y ± .37
3	$Y = 2.400(X_1)+.381(X2)-4.258$	15.5	.187	..843	Y ± .37

X_1 = month of year (i.e...6,7,8)
X_2 = air temperature average control plantation plots
Y = plot average, daily soil temperature 10 cm on control site

Plot	Equation	Y	Standard Error	R2	Confidence Interval_at X1, X2
	Soil Temperature Control Hardwood Plots (10 cm)				
1	$Y = 2.555(X_1)+.411(X_2)-7.920$	13.3	.157	.891	Y ± .31
2	$Y = 2.303(X_1)+.357(X_2)-6.873$	12.1	.149	.881	Y ± .30
3	$Y = 1.848(X_1)+.379(X_2)-4.818$	11.8	.140	.875	Y ± .28

X_1 = month of year (i.e...6,7,8)
X_2 = air temperature daily average control plantation plots
Y = plot average, daily soil temperature 10 cm on control tree site

Plot	Equation	Y	Standard Error	R2	Confidence Interval_at X1, X2
	Soil Temperature Antenna Hardwood Plots (5 cm)				
1	$Y = .687(X_1)+.769(X_2)-3.240$	11.7	.071	.974	Y ± .14
2	$Y = .590(X_1)+.803(X_2)-2.712$	12.1	.076	.971	Y ± .15
3	$Y = .119(X_1)+.970(X_2)-2.057$	12.4	.088	.966	Y ± .17

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 5 cm on ground site
Y = plot average daily soil temperature 5 cm on antenna tree site

Table 3. Equation 1987 to predict missing data.

1987 Missing Data Equations

Plot	Equation	Y	Standard Error	R2	Confidence Interval at X1, X2
	Soil Temperature Antenna Plantation Plots (5 cm)				
1	$Y = .232(X_1)+.921(X_2)-.427$	14.0	.054	.986	Y ± .11
2	$Y = .279(X_1)+.979(X_2)-1.419$	14.0	.080	.975	Y ± .16
3	$Y = .078(X_1)+.955(X_2)+1.117$	15.1	.066	.980	Y ± .13

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 5 cm on ground site
Y = plot average daily soil temperature 5 cm on antenna site

Plot	Equation	Y	Standard Error	R2	Confidence Interval at X1, X2
	Soil Temperature Antenna Hardwood Plots (10 cm)				
1	$Y = .294(X_1)+.872(X_2)-1.863$	11.9	.073	.974	Y ± .14
2	$Y = .425(X_1)+.817(X_2)-1.949$	11.8	.073	.972	Y ± .14
3	$Y = .053(X_1)+.982(X_2)-1.853$	12.0	.077	.973	Y ± .15

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 10 cm on ground site
Y = plot average daily soil temperature 10 cm on antenna tree site

Plot	Equation	Y	Standard Error	R2	Confidence Interval at X1, X2
	Soil Temperature Antenna Plantation Plots (10 cm)				
1	$Y =-.229(X_1)+1.058(X_2)+.990$	14.2	.045	.991	Y ± .09
2	$Y = .291(X_1)+.939(X_2)-1.057$	13.6	.046	.991	Y ± .09
3	$Y =-.423(X_1)+1.082(X_2)+2.433$	14.9	.068	.979	Y ± .13

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 10 cm on ground site
Y = plot average daily soil temperature 10 cm on antenna site

Table 4. Equation 1987 to predict missing data.

1987 Missing Data Equations

Plot	Equation	Y	Standard Error	R2	Confidence Interval at , X1, X2
	Soil Moisture Antenna Plantation Plots (5 cm)				
1	$Y = .288(X_1)+.691(X_2)+.653$	11.3	.128	.769	$Y \pm .25$
2	$Y = 1.313(X_1)+.860(X_2)-10.359$	10.3	.181	.709	$Y \pm .36$
3	$Y = .424(X_1)+.620(X_2)-.607$	10.2	.115	.751	$Y \pm .23$

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 5 cm on ground site
Y = plot average daily soil moisture 5 cm on antenna site

Plot	Equation	Y	Standard Error	R2	Confidence Interval at , X1, X2
	Soil Moisture Antenna Hardwood Plots (5 cm)				
1	$Y = 1.821(X_1)+.622(X_2)-12.122$	9.5	.287	.535	$Y \pm .57$
2	$Y = -.020(X_1)+.480(X_2)-4.727$	10.4	.104	.756	$Y \pm .21$
3	$Y = .205(X_1)+.451(X_2)+2.560$	9.6	.089	.739	$Y \pm .18$

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 5 cm on ground site
Y = plot average daily soil moisture 5 cm on antenna site

Plot	Equation	Y	Standard Error	R2	Confidence Interval at , X1, X2
	Soil Moisture Antenna Plantation Plots (10 cm)				
1	$Y = .059(X_1)+.418(X_2)+3.51$	9.6	.067	.662	$Y \pm .13$
2	$Y = .356(X_2)+4.266$	9.0	.074	.543	$Y \pm .15$
3	$Y = .060(X_1)+.538(X_2)+1.553$	9.2	.149	.400	$Y \pm .29$

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 10 cm on ground site
Y = plot average daily soil moisture 10 cm on antenna site

Table 5. Equation 1987 to predict missing data.

1987 Missing Data Equations

Plot	Equation	Y	Standard Error	R2	Confidence Interval at X1, X2
	Soil Moisture Antenna Hardwood Plots (10 cm)				
1	$Y = -3.443(X_1)+1.284(X_2)+7.070$	10.3	.220	.650	Y ± .45
2	$Y = .655(X_1)+.633(X_2)-1.147$	12.4	.248	.347	Y ± .49
3	$Y = .787(x1)+1.014(x2)-8.691$	11.0	.161	.724	Y ± .32

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 10 cm on ground site
Y = plot average daily soil moisture 10 cm on antenna site

Plot	Equation	Y	Standard Error	R2	Confidence Interval at X1, X2
	Soil Temperature Ground Plantation Plots (5 cm)				
1	$Y = .040(X_1)+.954(X_2)+.104$	12.5	.039	.990	Y ± .07
2	$Y = .0066(X_1)+.978(X_2)-.262$	12.2	.039	.990	Y ± .08
3	$Y = -.127(X_1)+1.030(X_2)+.553$	12.6	.048	.987	Y ± .10

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 5 cm on antenna site
Y = plot average daily soil temperature 5 cm on ground site

Plot	Equation	Y	Standard Error	R2	Confidence Interval at X1, X2
	Soil Temperature Ground Plantation Plots (10 cm)				
1	$Y = .065(X_1)+.976(X_2)-.779$	11.9	.029	.995	Y ± .06
2	$Y = .149(X_1)+.962(X_2)-1.030$	12.1	.032	.993	Y ± .06
3	$Y = .070(X_1)+.981(X_2)-.104$	12.7	.032	.993	Y ± .06

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil temperature 10 cm on antenna site
Y = plot average daily soil temperature 10 cm on ground site

Table 6. Equation 1987 to predict missing data.

1987 Missing Data Equations

Plot	Equation	Y	Standard Error	R2	Confidence Interval at X1, X2
	Soil Moisture Ground Plantation Plots (5 cm)				
1	$Y = -.951(X_1)+1.132(X_2)+7.549$	12.2	.133	.875	Y ± .26
2	$Y = -.5746(X_1)+.863(X_2)+13.741$	10.7	.148	.876	Y ± .29
3	$Y = -.329(X_1)+1.401(X_2)+1.357$	13.7	.157	.841	Y ± .31

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 5 cm on antenna site
Y = plot average daily soil moisture 5 cm on ground site

Plot	Equation	Y	Standard Error	R2	Confidence Interval at X1, X2
	Soil Moisture Ground Plantation Plots (10 cm)				
1	$Y = -.487(X_1)+1.367(X_2)+4.713$	13.6	.144	.649	Y ± .28
2	$Y = .150(X_1)+1.458(X_2)-2.001$	12.7	.147	.593	Y ± .29
3	$Y = 1.724(X_2)-2.065$	14.0	.138	.693	Y ± .27

X_1 = month of year (i.e...6,7,8)
X_2 = average daily soil moisture 10 cm on antenna site
Y = plot average daily soil moisture 10 cm on ground site

Plot	Equation	Y	Standard Error	R2	Confidence Interval at X1, X2
	Relative Humidity Ground Site				
	$Y = 1.211(X_1)+.953(X_2)-8.237$	76.9	.321	.970	Y ± .64

X_1 = month of year (i.e...6,7,8)
X_2 = daily relative humidity at antenna site
Y = daily relative humidity at ground site

Table 7. Equation 1987 to predict missing data.

1987 Missing Data Equations

Plot	Equation	Y	Standard Error	R2	Confidence Interval at X1, X2
	Relative Humidity Antenna Site				
	$Y = -.978(X_1)+.996(X_2)+10.655$	80.274	.328	.965	Y ± .65
	Relative Humidity Control Site				
	$Y = 3.386(X_1)+.629(X_2)$	61.6	1.150	.974	Y ± 2.29

Relative Humidity Antenna Site:

X_1 = month of year (i.e...6,7,8)
X_2 = daily relative humidity at ground site
Y = daily relative humidity at antenna site

Relative Humidity Control Site:

X_1 = month of year (i.e...6,7,8)
X_2 = daily relative humidity at Crystal Falls DNR station
Y = daily relative humidity at control site

Table 8 Monthly ambient air temperatures, soil temperatures, and soil moistures (1985)

1985 GROWING SEASON	AIR TEMP. (deg. C.)	5 cm SOIL TEMP. (deg. C)	5 cm SOIL MOIST. (percent)	10 cm SOIL TEMP. (deg. C)	10 cm SOIL MOIST. (percent)
GROUND SITE - PLANTATION					
APRIL	4.9	4.1		3.7	
MAY	11.2	12.9		12.5	
JUNE	13.3	15.8		15.1	
JULY	16.8	17.9		17.5	
AUGUST	15.6	16.4		16.1	
SEPT.	12.1	13.4		13.4	
OCT.	6.1	7.2		7.3	
$\bar{X}$=	11.4	12.5		12.2	
ANTENNA SITE - PLANTATION					
APRIL	4.8	4.5		3.4	
MAY	11.3	13.4		13.0	
JUNE	13.2	15.9		15.4	
JULY	16.6	18.7		18.4	
AUGUST	15.7	17.1		16.8	
SEPT.	12.2	13.8		13.8	
OCT.	6.4	7.1		7.3	
$\bar{X}$=	11.5	12.9		12.6	
ANTENNA SITE - HARDWOOD					
APRIL	4.9	1.8		1.6	
MAY	11.3	10.1		9.7	
JUNE	13.3	11.8		11.4	
JULY	16.6	15.1		14.6	
AUGUST	15.5	14.3		14.5	
SEPT.	12.1	11.6		12.2	
OCT.	6.3	6.3		7.0	
$\bar{X}$=	11.4	10.1		10.1	
CONTROL SITE - PLANTATION					
APRIL	5.2	3.4		2.4	
MAY	12.2	12.7		12.7	
JUNE	13.9	15.2		15.2	
JULY	17.2	18.2		18.2	
AUGUST	15.9	16.8		16.8	
SEPT.	12.3	13.8		14.1	
OCT.	6.6	7.0		7.2	
$\bar{X}$=	11.9	12.5		12.4	
CONTROL SITE - HARDWOOD					
APRIL	5.7	2.1		1.9	
MAY	12.6	10.3		10.0	
JUNE	14.1	12.1		11.8	
JULY	17.6	15.6		15.2	
AUGUST	16.1	15.3		15.2	
SEPT.	12.6	13.1		13.2	
OCT.	7.0	7.4		7.6	
$\bar{X}$=	12.3	10.9		10.7	

Table 9 Precipitation totals, solar radiation, air temperature (30 cm. above the ground), and relative humidity (1985)

1985 GROWING SEASON	MONTHLY PRECIPITATION (in.)	SOLAR RADIATION	AIR TEMP. 30 CM. (deg. C.)	RELATIVE HUMIDITY (percent)
		GROUND SITE		
APRIL	3.33	381.1 (Langley/		
MAY	4.93	435.8 Day)		
JUNE	1.70	519.8		85.6
JULY	2.66	553.6		78.0
AUGUST	5.17			76.5
SEPT.	5.70	255.8		82.1
OCT.	3.19	220.4		75.8
TOTAl=	26.68	473.7		79.6
		ANTENNA SITE		
APRIL	3.33	(Eins.	5.3	
MAY	4.94	/Day)	11.9	
JUNE	1.84	3.3	13.0	79.5
JULY	2.79	3.2	16.5	71.7
AUGUST	5.17	2.2	15.4	71.6
SEPT.	5.92	1.6	12.2	82.4
OCT.	3.09	3.7	6.2	73.1
TOTAL=	27.08 $\bar{X}$=	2.8	11.5	75.7
		CONTROL SITE		
APRIL	1.72		6.1	
MAY	4.19		12.7	
JUNE	2.13	2.2	14.2	
JULY	.85	2.0	17.8	77.4
AUGUST	3.14	1.2	16.0	79.5
SEPT.	7.00		12.3	77.5
OCT.	2.64		6.5	75.3
TOTAl=	21.67 $\bar{X}$=		12.2	77.4

Table 10 Monthly ambient air temperatures, soil temperatures, and soil moistures (1986)

1986 GROWING SEASON	AIR TEMP. (deg. C.)	5 cm SOIL TEMP. (deg. C)	5 cm SOIL MOIST. (percent)	10 cm SOIL TEMP. (deg. C)	10 cm SOIL MOIST. (percent)
GROUND SITE - PLANTATION					
APRIL	6.1	6.3	13.5	5.8	16.3
MAY	12.8	14.0	12.9	13.2	17.8
JUNE	14.1	16.4	10.4	16.0	12.5
JULY	18.9	19.6	9.2	19.1	9.2
AUGUST	15.3	16.3	12.7	16.1	12.7
SEPT.	11.0	13.1	17.6	13.0	18.9
OCT.	5.5	7.6	15.9	7.6	19.0
$\bar{X}$=	12.0	13.3	13.2	13.0	15.2
ANTENNA SITE - PLANTATION					
APRIL	6.0	6.4	10.0	6.1	10.2
MAY	13.2	14.5	9.9	14.2	9.8
JUNE	14.6	16.3	6.6	16.3	6.8
JULY	19.2	20.0	5.3	20.0	7.9
AUGUST	15.3	16.6	8.8	16.7	8.0
SEPT.	10.5	13.3	12.4	13.3	10.6
OCT.	5.7	7.5	11.2	7.5	10.8
$\bar{X}$=	12.1	13.5	9.2	13.4	9.2
ANTENNA SITE - HARDWOOD					
APRIL	6.0	4.9	11.0	4.2	11.1
MAY	13.1	11.0	12.7	10.7	11.1
JUNE	14.2	12.7	8.3	12.4	8.1
JULY	18.8	16.5	5.7	16.3	6.1
AUGUST	15.3	13.9	9.5	13.8	8.4
SEPT.	11.0	11.7	13.5	11.6	12.4
OCT.	5.6	7.7	12.2	7.4	12.7
$\bar{X}$=	12.0	11.2	10.4	10.9	10.0
CONTROL SITE - PLANTATION					
APRIL	6.5	7.3	19.0	6.8	15.7
MAY	12.2	13.5	19.8	13.1	18.0
JUNE	14.9	16.2	11.6	15.9	9.2
JULY	19.3	19.8	12.7	19.4	11.3
AUGUST	15.3	17.1	11.1	17.1	12.2
SEPT.	13.0	13.2	18.1	13.3	17.2
OCT.	6.6	7.2	19.7	7.4	18.5
$\bar{X}$=	12.5	13.5	16.0	13.3	14.6
CONTROL SITE - HARDWOOD					
APRIL	6.9	4.9	18.4	4.7	16.3
MAY	13.7	11.6	16.4	11.2	16.4
JUNE	15.0	13.3	11.6	13.1	9.6
JULY	19.2	17.1	8.8	16.6	8.6
AUGUST	15.6	14.8	8.9	14.5	7.1
SEPT.	13.1	12.4	16.6	12.2	12.3
OCT.	6.6	7.8	17.8	7.8	18.0
$\bar{X}$=	12.9	11.7	14.1	11.4	12.6

Table 11 Precipitation totals, solar radiation, air temperature (30 cm. above the ground), and relative humidity (1986)

1986 GROWING SEASON	MONTHLY PRECIPITATION (cm.)	SOLAR RADIATION	AIR TEMP. 30 CM. (deg. C.)	RELATIVE HUMIDITY (percent)
		GROUND SITE		
APRIL	1.21	373.9 (Langley/		58.8
MAY	0.00	473.8 Day)		60.4
JUNE	1.06	498.5		71.2
JULY	1.80	387.8		76.8
AUGUST	2.70	389.3		68.5
SEPT.	3.16	233.5		65.7
OCT.	3.18	215.9		85.3
TOTAL=	13.11 $\bar{X}$	367.5		69.5
		ANTENNA SITE		
APRIL	.50	19.0 (Eins. 6.6	63.6	
MAY	.01	16.3 /Day)	13.4	67.3
JUNE	.98	1.6	14.1	76.2
JULY	1.84	1.1	18.5	85.8
AUGUST	2.70		15.1	74.6
SEPT.	3.16		10.9	71.6
OCT.	3.22		5.7	90.6
TOTAL=	12.41 $\bar{X}$=	9.5	12.0	75.7
		CONTROL SITE		
APRIL	.58	15.4	6.7	53.3
MAY	.34	11.9	13.4	58.7
JUNE	1.86	1.3	14.5	69.6
JULY	2.33	1.2	18.9	75.8
AUGUST	2.24		15.4	
SEPT.	3.08		12.9	
OCT.	2.90		6.9	
TOTAL=	13.33 $\bar{X}$=	7.5	12.7	

Table 12 Monthly ambient air temperatures, soil temperatures, and soil moistures (1987)

1987 GROWING SEASON	AIR TEMP. (deg. C.)	5 cm SOIL TEMP. (deg. C)	5 cm SOIL MOIST. (percent)	10 cm SOIL TEMP. (deg. C)	10 cm SOIL MOIST. (percent)
			GROUND SITE - PLANTATION		
APRIL	8.0	7.5	16.3	7.1	14.2
MAY	11.9	12.9	17.2	12.4	15.9
JUNE	17.4	17.9	15.9	17.6	14.9
JULY	19.2	18.8	14.2	18.6	15.0
AUGUST	16.3	17.3	10.4	17.2	12.9
SEPT.	12.6	13.7	9.2	13.6	11.2
OCT.	3.2	6.1	12.2	6.0	15.5
$\bar{X}$=	12.7	13.5 13.6	13.2	14.2	
			ANTENNA SITE - PLANTATION		
APRIL	8.3	7.8	11.6	7.7	10.0
MAY	12.2	12.9	12.3	12.9	10.0
JUNE	17.7	18.0	12.4	17.9	10.2
JULY	19.2	19.1	11.7	19.0	10.3
AUGUST	16.7	17.8	9.3	17.6	9.6
SEPT.	13.0	14.0	8.7	13.8	8.4
OCT.	3.4	6.2	12.8	5.8	10.1
$\bar{X}$=	12.9	13.7	11.3	13.5	9.8
			ANTENNA SITE - HARDWOOD		
APRIL	8.3	6.0	10.5	5.8	11.4
MAY	12.1	10.2	12.1	10.2	10.3
JUNE	17.3	15.1	10.2	15.0	11.4
JULY	18.7	16.9	13.0	16.8	11.3
AUGUST	16.4	16.0	10.1	15.8	10.9
SEPT.	12.9	12.8	8.4	12.6	9.6
OCT.	3.4	5.9	11.5	6.1	13.4
$\bar{X}$=	12.7	11.8	10.8	11.7	11.2
			CONTROL SITE - PLANTATION		
APRIL	8.8	7.0	10.3	6.8	10.2
MAY	13.0	12.6	9.3	12.4	13.8
JUNE	18.6	17.9	10.8	17.7	15.4
JULY	19.7	19.3	15.2	19.0	17.5
AUGUST	17.3	18.3	18.5	18.3	18.0
SEPT.	13.6	14.2	14.6	14.3	15.8
OCT.	3.9	6.2	16.2	6.7	15.1
$\bar{X}$=	13.6	13.6	13.5	13.6	15.1
			CONTROL SITE - HARDWOOD		
APRIL	9.2	6.1	12.3	5.6	10.9
MAY	13.1	10.5	12.8	9.6	15.1
JUNE	18.3	15.6	12.3	14.2	12.6
JULY	19.2	17.5	11.6	16.3	14.6
AUGUST	17.2	16.8	12.1	15.9	12.9
SEPT.	13.5	13.4	6.2	12.6	9.3
OCT.	4.1	6.3	9.2	6.2	13.7
$\bar{X}$=	13.5	12.3	10.9	11.5	12.7

Table 13 Precipitation totals, solar radiation, air temperature (30 cm. above the ground), and relative humidity (1987)

1987 GROWING SEASON	MONTHLY PRECIPITATION (in.)		SOLAR RADIATION	AIR TEMP. 30 CM. (deg. C.)	RELATIVE HUMIDITY (percent)
			GROUND SITE		
APRIL	0.90		444.5 (Langley/		64.1
MAY	3.23		495.9 Day)		66.1
JUNE	2.42		528.2		76.5
JULY	6.02				83.6
AUGUST	2.72		352.2		87.6
SEPT.	2.04		294.3		86.7
OCT.	2.26		152.3		85.2
TOTAL=	19.59	$\bar{X}$	377.9		78.5
			ANTENNA SITE		
APRIL	0.97		19.1 (Eins.		70.7
MAY	3.28		13.3 /Day)		71.9
JUNE	2.42		1.9		81.3
JULY	6.02		2.3		87.5
AUGUST	3.10				90.2
SEPT.	2.28				88.1
OCT.	2.49				85.9
TOTAL=	20.56	$\bar{X}$	9.2		82.2
			CONTROL SITE		
APRIL	.82		12.4		56.5
MAY	3.27		13.2		55.6
JUNE	1.53		.5		67.9
JULY	5.49		1.4		70.3
AUGUST	4.10		1.3		72.3
SEPT.	1.97		1.1		75.1
OCT.	2.39		3.5		78.5
TOTAL=	19.57	$\bar{X}$	4.8		68.0

Table 14. Mean soil nutrient values (kg/ha) Hardwoods 1985-1986

ANTENNA

	1985					1986				
	Ca	Mg	K	P[a]	N	Ca	Mg	K	P[b]	N
May	477.69	61.71	59.88	2.58	1302.93	-	-	-	-	-
Jun	602.71	79.01	74.15	2.94	1825.90	341.60	55.37	52.91	614.58	1230.01
Jul	508.08	74.77	77.58	5.46	1420.07	275.02	58.63	42.95	593.87	1410.39
Aug	514.44	62.52	58.62	3.11	983.40	234.13	49.33	49.85	588.25	1035.15
Sep	491.64	61.32	61.88	2.64	945.88	247.20	48.24	43.94	497.21	1059.84
Oct	480.85	60.19	64.59	3.28	1330.39	-	-	-	-	-

CONTROL

	1985					1986				
	Ca	Mg	K	P[a]	N	Ca	Mg	K	P[b]	N
May	811.59	112.77	84.62	2.94	1648.35	-	-	-	-	-
Jun	813.78	99.21	94.69	2.86	1527.05	401.52	49.82	72.22	888.97	1170.69
Jul	1077.88	127.41	136.33	3.26	2027.19	443.45	102.91	59.14	917.36	1197.46
Aug	831.56	92.24	91.92	2.73	1235.71	472.96	190.34	54.60	839.36	1099.73
Sep	618.13	77.29	84.93	1.97	1149.58	480.73	97.13	67.94	791.83	1300.83
Oct	674.48	90.48	83.91	3.01	1431.37	-	-	-	-	-

a Water soluble P

b Total P

Table 15. Mean soil nutrient values (kg/ha) Plantations 1985-1986

	1985					1986				
	Ca	Mg	K	P[a]	N	Ca	Mg	K	P[b]	N
GROUND										
Jun	-	-	-	-	-	514.89	80.81	78.11	617.31	1685.33
Jul	1226.99	141.35	140.95	4.32	2239.96	464.27	82.91	83.85	637.74	1363.67
Aug	-	-	-	-	-	549.71	80.72	77.58	595.85	999.26
Sep	-	-	-	-	-	695.13	94.35	78.83	540.35	1377.79
ANTENNA										
Jun	-	-	-	-	-	386.97	48.24	56.35	746.04	1315.21
Jul	723.59	93.85	101.19	4.39	1740.58	373.33	69.55	57.21	735.16	1350.13
Aug	-	-	-	-	-	266.77	40.24	48.90	760.77	1045.94
Sep	-	-	-	-	-	586.29	76.45	72.44	697.53	1286.32
CONTROL										
Jun	-	-	-	-	-	556.39	59.24	94.60	870.15	1393.19
Jul	1273.29	136.58	124.42	3.95	2247.83	579.69	84.02	68.84	889.82	1381.00
Aug	-	-	-	-	-	674.31	93.18	68.82	816.36	1045.75
Sep	-	-	-	-	-	789.41	92.36	89.28	1026 68	1426.69

[a] Water soluble P

[b] Total P

APPENDIX C

Tension Moisture Equations

Soil moisture content vs tension curves were developed from each plot to predict tension from soil moisture content. Soil from the samples taken during the July soil probe collection was used for the analysis. Five samples (reps) from the each plot were collected, composited, and then mixed to ensure equal representation.

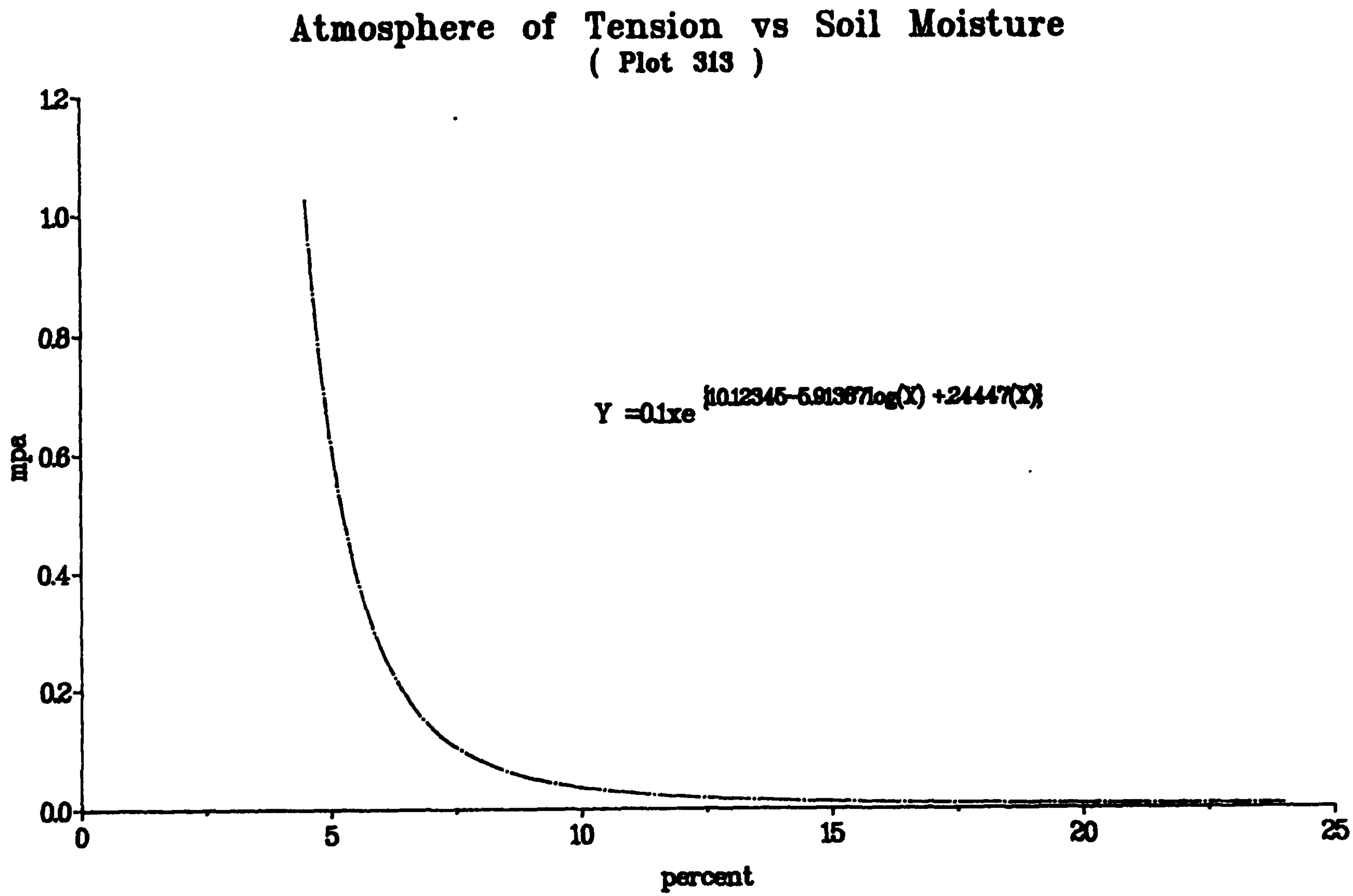
Two replicates of the composited soil from each plot were saturated and then subjected to different atmospheric pressures (.01, .033, .1, .3, .5, 1.5 Mpa). This procedure forces the moisture out of the samples until an equilibrium is reached. At equilibrium the pressure applied is equal to the the tension the remaining water is held at within the soil. Samples are then weighed and dried at 105 ^{o}C for determination of moisture content.

From this data, equations were developed using tension as the dependent variable and moisture content as the independent variable. Differences among coefficients among the plots within sites were significant ($p=0.05$). Thus regression equations were developed for each individual plot. A two variable equation was fitted to the data using moisture content and the natural log of moisture content as the independent variables. This equation had the best fit when compared with inverse and exponential equations. The equations fit the curves well at the lower tensions (.01 to .3 -Mpa) which is the area most critical to plant growth. The equations are given in Table 1. A graph of a plot developed from the curves is also presented in Figure 1.

Table 1. Equations to predict atmospheres at different soil moisture contents.

Plot	Equation	Standard Error	R2	CI	n
111	$8.038-4.552X_1+.150X_2$	.128	.996	$\pm$.336	11
112	$8.682-5.341X_1+.247X_2$	.102	.967	$\pm$.227	12
113	$6.546-3.806X_1+1.047X_2$	.073	.983	$\pm$.163	12
121	$8.645-4.822X_1+.152X_2$	.080	.979	$\pm$.178	12
122	$11.718-7.016X_1+.335X_2$	.047	.993	$\pm$.105	12
123	$11.575-7.205X_1+.367X_2$	.032	.997	$\pm$.071	12
211	$7.435-5.519X_1+.313X_2$	.146	.933	$\pm$.325	12
212	$9.460-7.823X_1+.632X_2$	.145	.933	$\pm$.323	12
213	$8.983-7.275X_1+.547X_2$	.176	.914	$\pm$.461	11
221	$9.985-7.130X_1+.466X_2$	.042	.994	$\pm$.094	12
222	$8.013-5.912X_1+.373X_2$	.069	.981	$\pm$.154	12
223	$7.762-5.885X_1+.353X_2$	.101	.968	$\pm$.225	12
311	$10.152-6.342X_1+.300X_2$	.132	.954	$\pm$.346	11
312	$9.487-5.676X_1+.255X_2$	.120	.954	$\pm$.267	12
313	$10.123-5.914X_1+.244X_2$	.104	.965	$\pm$.232	12
321	$10.762-7.802X_1+.539X_2$	.088	.975	$\pm$.196	12
322	$9.916-6.330X_1+.341X_2$	.083	.978	$\pm$.185	12
323	$9.44607-5.72261X_1+.27204X_2$	.094	.972	$\pm$.209	12

X_1=Nautural Log Moisture Content (%)
X_2=Moisture Content (%)



Atmosphere of Tension vs Soil Moisture
(Plot 313)
Y =0.1xe {10.12345-5.91367log(X) +.24447(X)}
mpa
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
percent

APPENDIX D

Prior to the 1987 growing season, a general decline in annual diameter growth occurred on the hardwood plots in successive years (Table 2.4). This decline could have been natural in origin or caused, at least in part, by the impact of human activity on the study plots. A small study examining growth rates in the stand surrounding the hardwood study plots to determine if the same trend was present there was performed in early 1987.

A sample of 30 trees (or fewer if there were fewer than 30 trees of a species on a study site) was selected from the surrounding stand for each species on each site. These sample trees were stratified into diameter classes to match the diameter distribution on the study plots. Two cores were taken at breast height from each sample tree at a right angle to each other. Each core was sealed in a plastic straw, labeled, and stored in a refrigerator until measurement, usually the following day. Annual ring widths for each of the last five years on each core were measured to the nearest 0.03 cm using a microscope at 100 power. Diameter growth for each sample tree and year was determined and means were calculated by species and site. These means were then compared to the growth rates on the study plots using a two-sample t-test.

The results of the analysis are given in Table B1. For the most part there seems to be no difference ($p=0.05$) between on and off plot growth rates. There are a few exceptions and these are probably explained through microsite effects. Paper birch at the control site grew more off the study plots in 1985 and 1986. Sample trees for birch were selected in a small birch cove, indicating microsite conditions favoring paper birch growth. These microsite factors could include a higher site index and reduced competition from other species. In any case, the off plot trees showed declining growth rates from 1984 to 1986 as did the trees on the study plots.

For red maple, sample trees on both sites were located some distance from the study plots due to difficulties in meeting the diameter distribution requirements of the sample. Microsite factors were again different, particularly the slope and elevation of the sample tree locations. Even though the 1984 growth was different in the sample trees than on the control site, growth declined each year of the study. On the antenna site, the sample tree growth differed from the study plot growth in both 1984 and 1986 but was lower in 1984 and higher in 1986. This is probably due to the microsite differences of the sample tree locations. Due to the results on the control site and the results from the other three species, no attempt will be made to improve the sample for red maple on the antenna site.

The sample tree growths did not differ from the growths on the study sites for aspen and the decline across years was evident. For northern red oak, the growth rates differed on the control site in 1984 but the results across years did not indicate that activity on the plots was significantly impacting growth of the study trees.

Table 1. Off plot hardwood diameter growth (cm) for study years 1984 through 1986.

Species	Number of Trees Sampled	1984	1985	1986
Oak				
Antenna	28	.23	.22	.19
Control	30	.24*	.22	.17
Paper Birch				
Antenna	7	.18	.15	.14
Control	34	.12	.12*	.11*
Aspen				
Antenna	13	.31	.31	.24
Control	31	.34	.32	.22
Maple				
Antenna	29	.14*	.18	.13*
Control	15	.19*	.17	.15

*Indicates growth significantly different from the study plots (p=.05).

This study, though small in size, did not indicate a need for further examination of the impact of human activity on the diameter growth of the banded trees at this time. The general growth declines noted on the study plots were also present in the surrounding stand where there was no regular human activity. In any case, increased growth rates were observed in 1987 for red maple and northern red oak reversing the declining trend of the previous years.

APPENDIX E

Table 1. Intertree competition indices tested on hardwood sites.

Source	Weighting Factors	Index
Lorimer 1983	7.62m & BAF5 m^2/ha	$\sum_{j=1}^{n} D_j/D_i$
Daniels et al. 1986	7.62m & BAF5 m^2/ha	$\dfrac{D_i^2}{\left(\sum_{j=1}^{n} D_j^2\right)/n}$
Hegyi 1974	7.62m & BAF5 m^2/ha	$\sum_{j=1}^{n} \dfrac{D_j/Di}{L_{ij}}$
Spurr 1962	7.62m & BAF5 m^2/ha	$75.625\left[\dfrac{\sum_{j=1}^{n}[(D_j/L_{ij})^2(j-\frac{1}{2})]}{n}\right]$
Spurr 1962	7.62m & BAF5 m^2/ha	$75.625\left[\dfrac{\sum_{j=1}^{n}[(D_j/L_{ij})^2(j+\frac{1}{2})]}{n}\right]$
Bella 1971	ex=1,1.5,2,2.5,3	$\sum_{j=1}^{n} [(a_{ij}/A_i)(D_j/D_i)^{ex}]$
Arney 1973	---	$\left(\dfrac{\sum_{j=1}^{n} a_{ij} + A_i}{A_i}\right) 100$
Brown 1965	---	Area Potentially Available (APA)

Moore and Budelsky 1973	$wt = \dfrac{D_j}{D_i+D_j}$	APA
Pelz 1978	$wt = \dfrac{D_j^2}{D_i^2+D_j^2}$	APA
Modification of Nance et al. 1987	CF	APA
Modification of Nance et al. 1987	$CF, wt = \dfrac{D_j}{D_i+D_j}$	APA
Modification of Nance et al. 1987	$CF, wt = \dfrac{D_j^2}{D_i^2+D_j^2}$	APA

Notation:

- D_i - Subject tree DBH
- D_j - Competitor tree DBH
- L_{ij} - Distance between competitor and subject tree
- n - Number of competitors in a plot
- a_{ij} - Area of influence zone overlap between competitor and subject tree
- A_i - Area of subject tree influence zone
- APA - Area of polygon formed when perpendicular bisectors are drawn between a subject tree and it's competitors
- wt - Weighting factor to determine distance from subject tree to polygon side
- CF - Constraining factor, maximum distance to any polygon side, open grown crown radius of species

APPENDIX F

Average plant moisture stress values 1985-1987 (-Mpa).

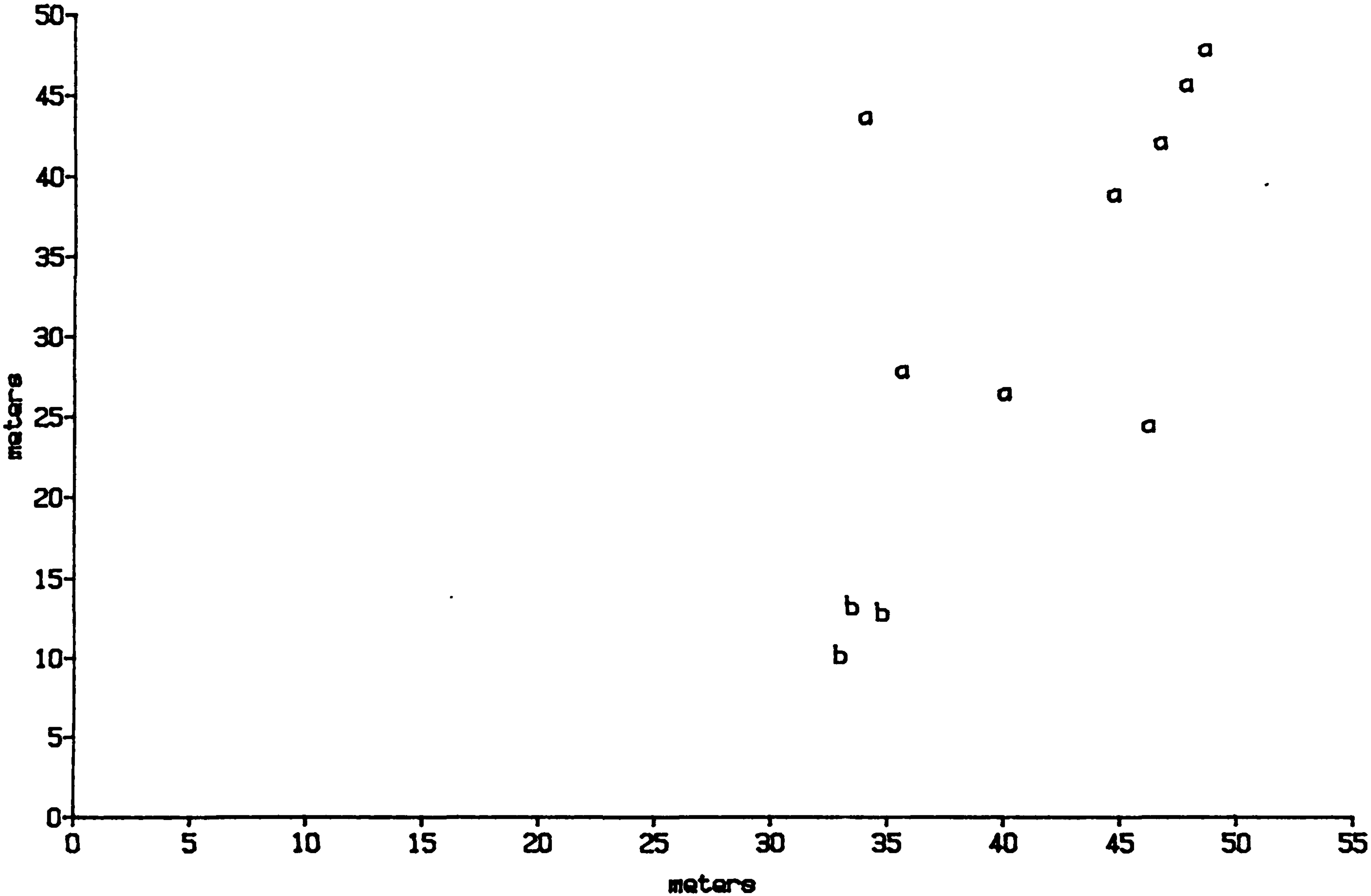
	1985			1986			1987		
Week of	**Ground**	**Antenna**	**Control**	**Ground**	**Antenna**	**Control**	**Ground**	**Antenna**	**Control**
5/25	2.32	2.17	1.10	.68	.77	.70	.23	.26	.24
6/10	--	--	--	.62	.68	.80	.19	.20	.19
6/24	.50	.50	.64	.73	.86	.74	.23	.15	.24
7/8	--	--	--	.66	.72	.74	.26	.26	.50
7/22	.63	.65	.68	.59	.63	.93	.25	.19	.21
8/5	--	--	--	.45	.46	.62	.42	.27	.43
8/19	.59	.57	.64	.37	.39	.56	.54	.66	.43
9/2	--	--	--	.39	.36	.47	.81	.65	.75
9/20	1.94	2.15	2.25	--	--	--	.77	.69	.62

Note: Xylem water was frozen during the weeks of 5/25 and 9/20 1985 which results in artificially high PMS values.

APPENDIX G

Figure 1

LOCATION OF ARMILLARIA CLONES
GROUND SITE (111) - AS OF DECEMBER 1987
Different letters indicate separate clones.



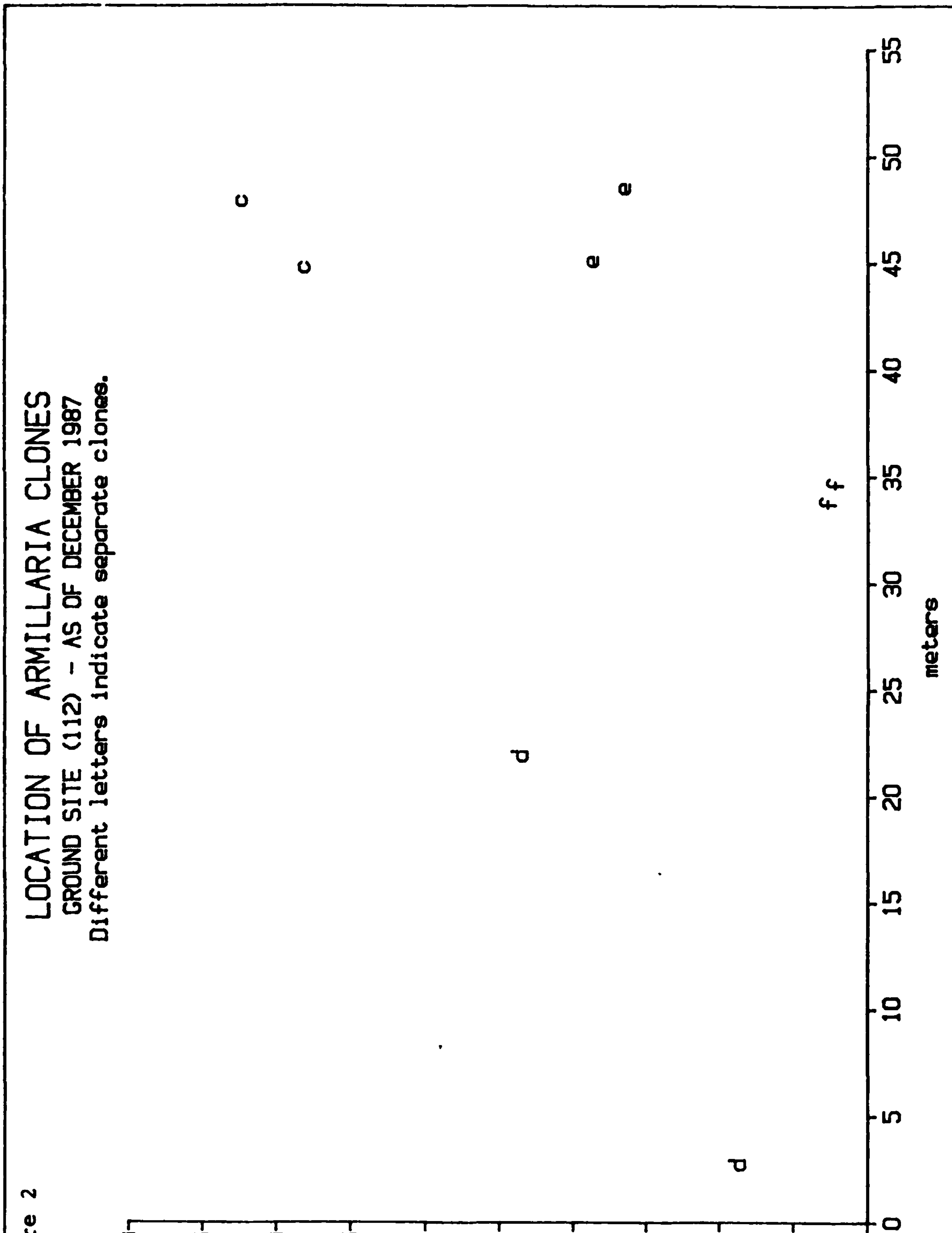
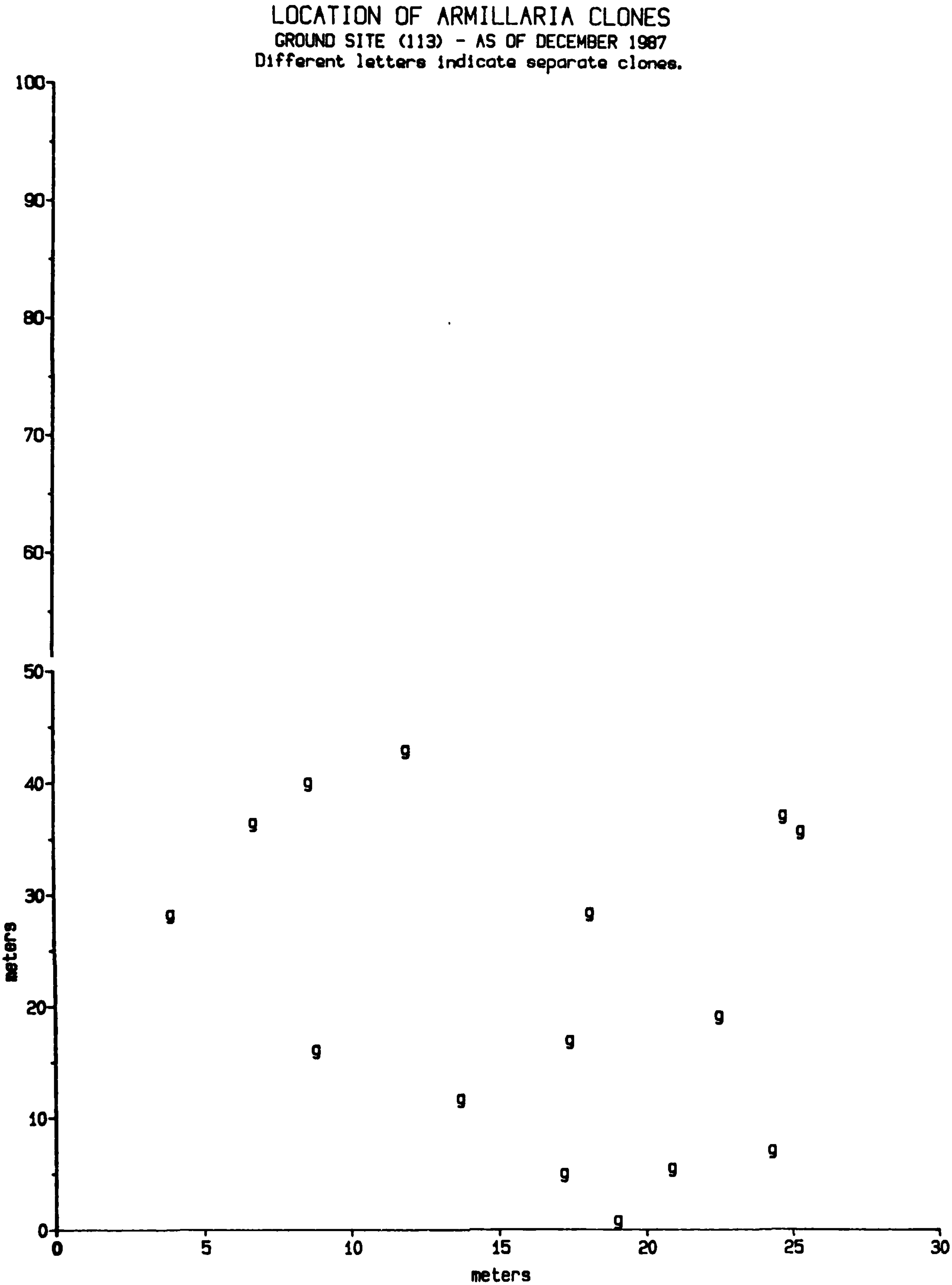


Figure 2
LOCATION OF ARMILLARIA CLONES
GROUND SITE (112) - AS OF DECEMBER 1987
Different letters indicate separate clones.
meters
meters
0
5
10
15
20
25
30
35
40
45
50
55
c
c
d
d
e
e
f f

Figure 3



LOCATION OF ARMILLARIA CLONES
GROUND SITE (113) - AS OF DECEMBER 1987
Different letters indicate separate clones.
100
90
80
70
60
50
40
30
20
10
0
meters
g
0
5
10
15
20
25
30
meters

Figure 4

LOCATION OF ARMILLARIA CLONES
ANTENNA SITE (211) - AS OF DECEMBER 1987
Different letters indicate separate clones.

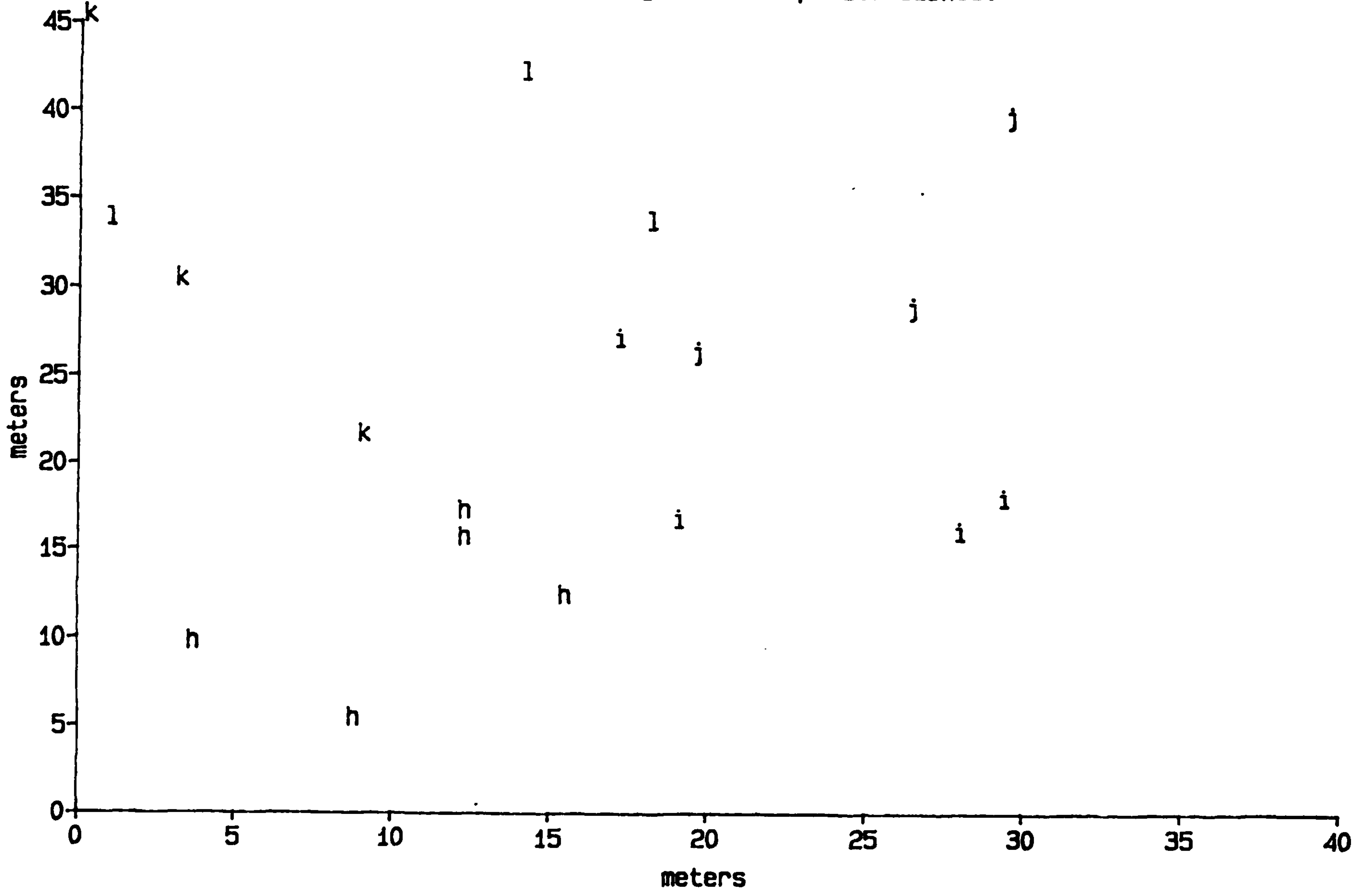


Figure 5

LOCATION OF ARMILLARIA CLONES

ANTENNA SITE (212) - AS OF DECEMBER 1987

Different letters indicate separate clones.

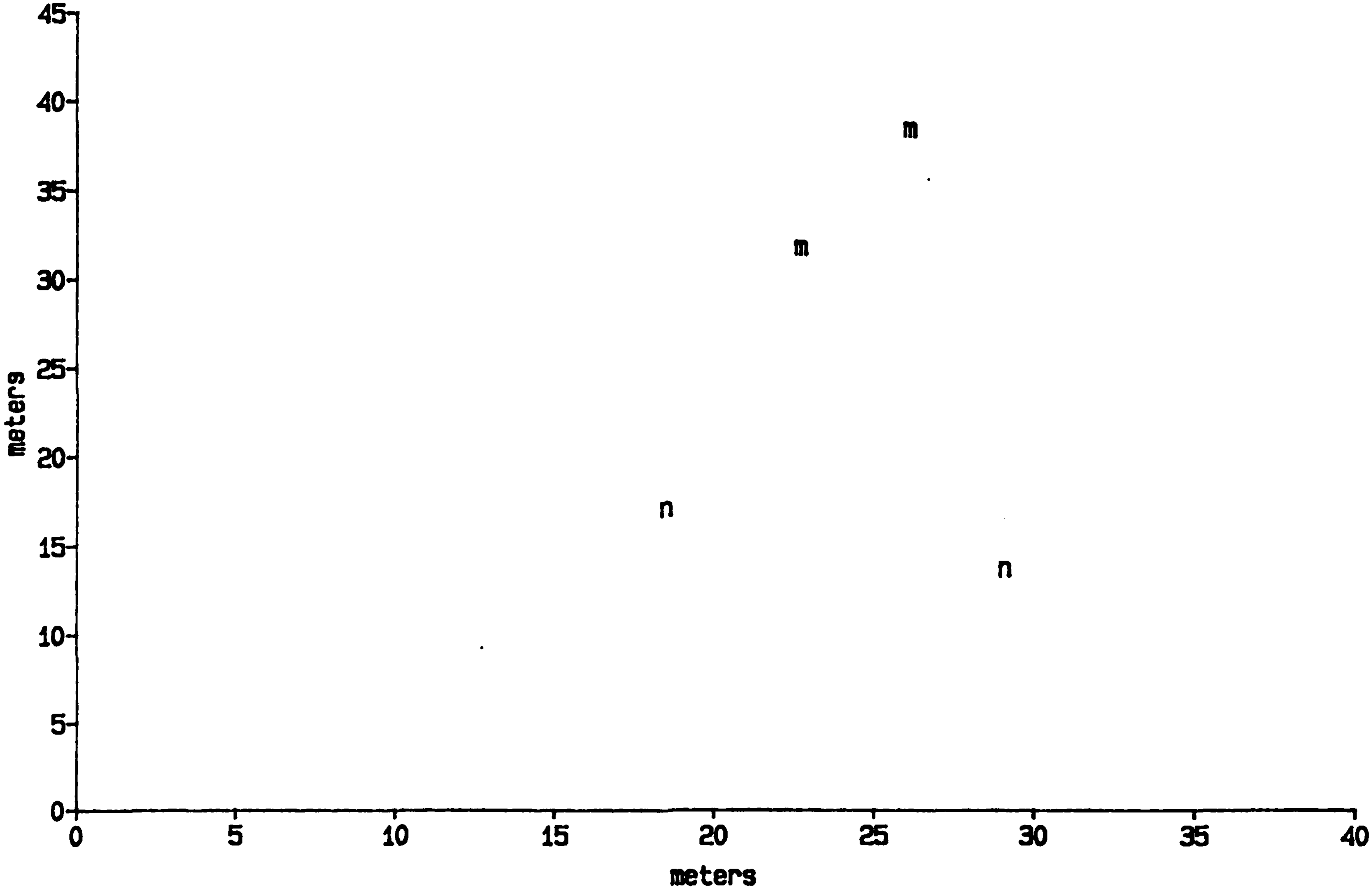


Figure 6

LOCATION OF ARMILLARIA CLONES

ANTENNA SITE (213) - AS OF DECEMBER 1987

Different letters indicate separate clones.

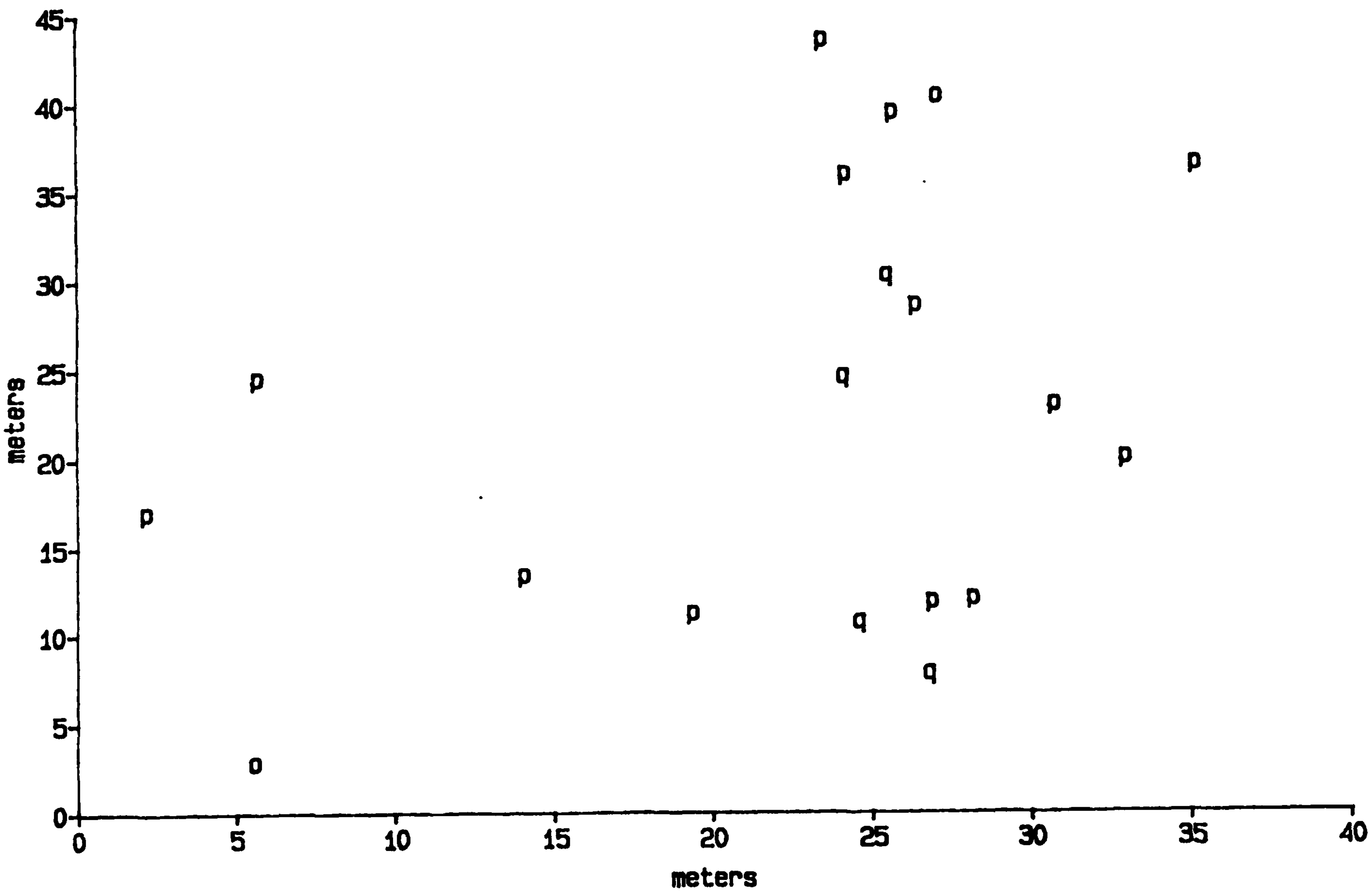


Figure 7

LOCATION OF ARMILLARIA CLONES

CONTROL SITE (311) - AS OF DECEMBER 1987

Different letters indicate separate clones.

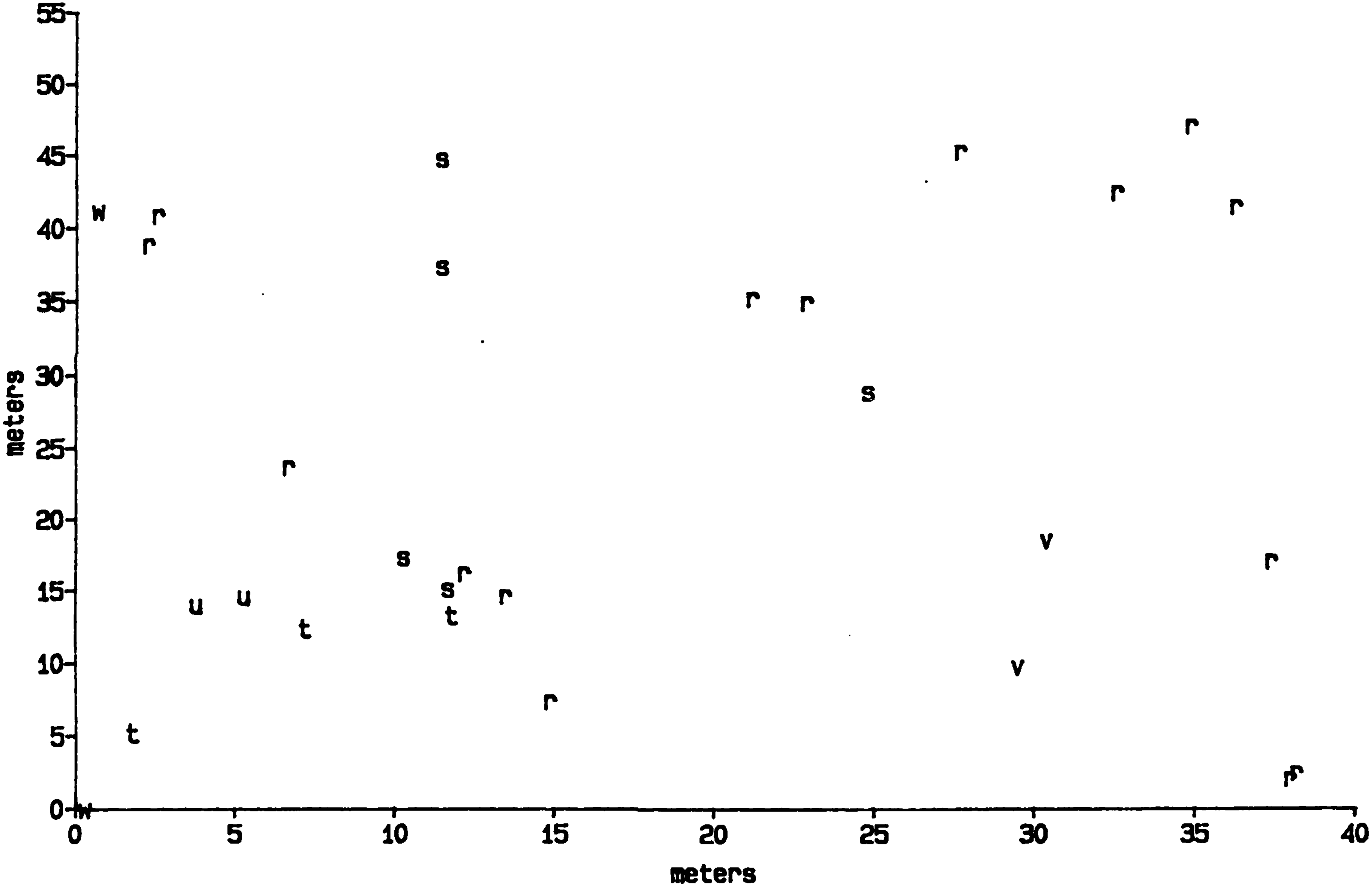


Figure 8

LOCATION OF ARMILLARIA CLONES

CONTROL SITE (312) - AS OF DECEMBER 1987

Different letters indicate separate clones.

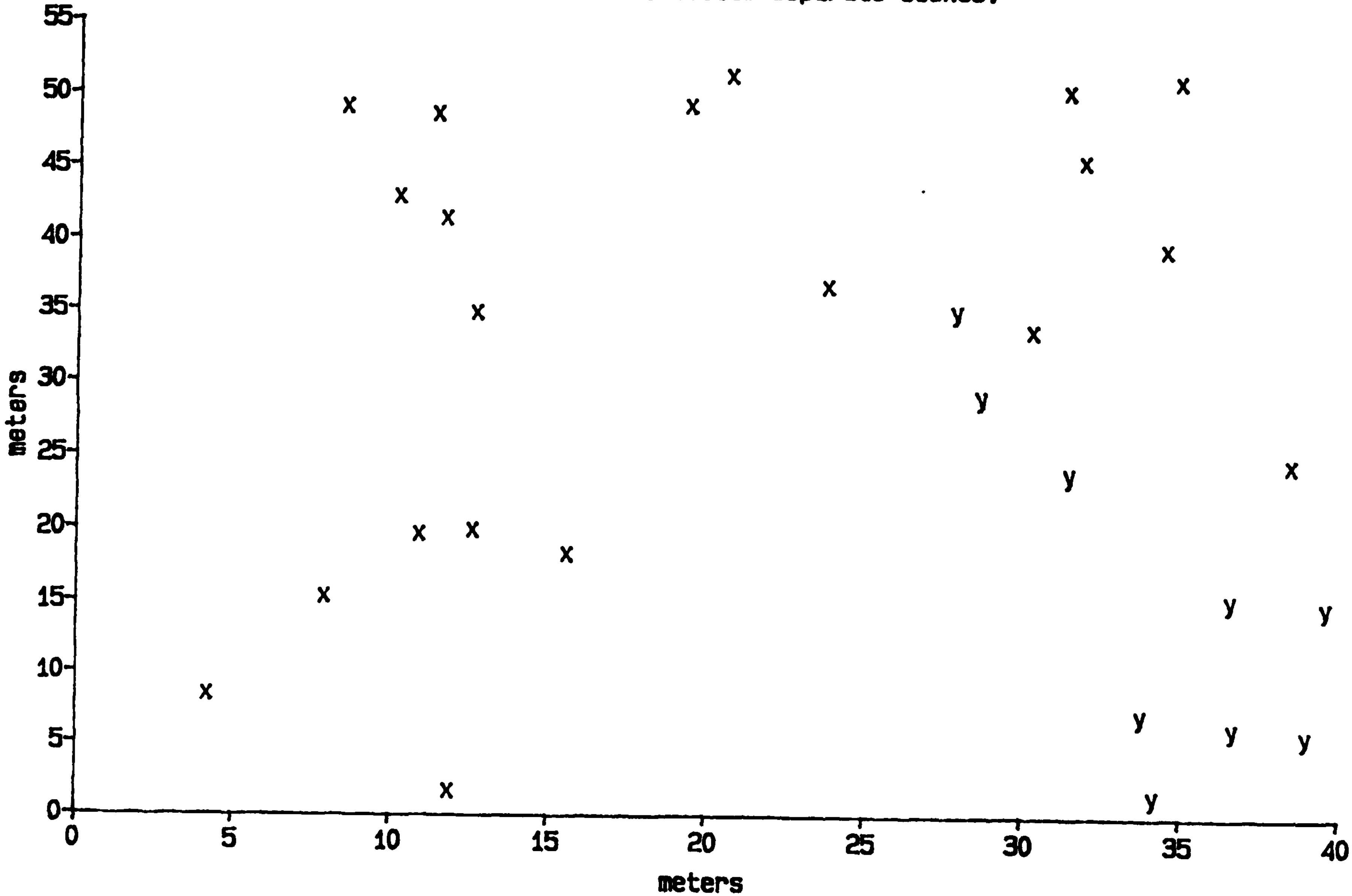
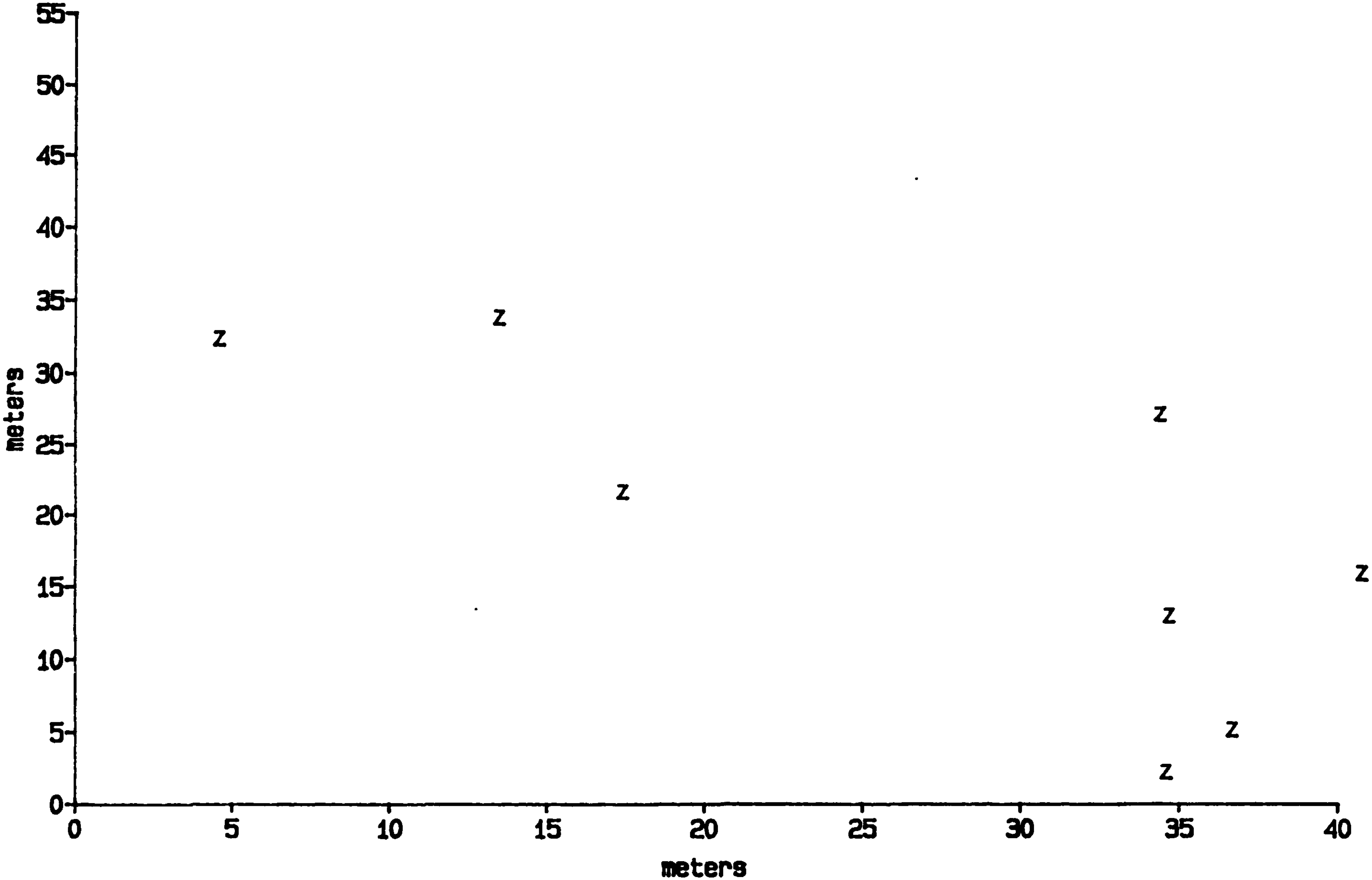


Figure 9

LOCATION OF ARMILLARIA CLONES

CONTROL SITE (313) - AS OF DECEMBER 1987

Different letters indicate separate clones.



APPENDIX H

Figure 1

STUMPS AND ARMILLARIA MORTALITY SEEDLINGS

GROUND SITE (111) - AS OF DECEMBER 1987

A-Aspen O-Oak M-Maple P-Pine B-Birch X-Mortality

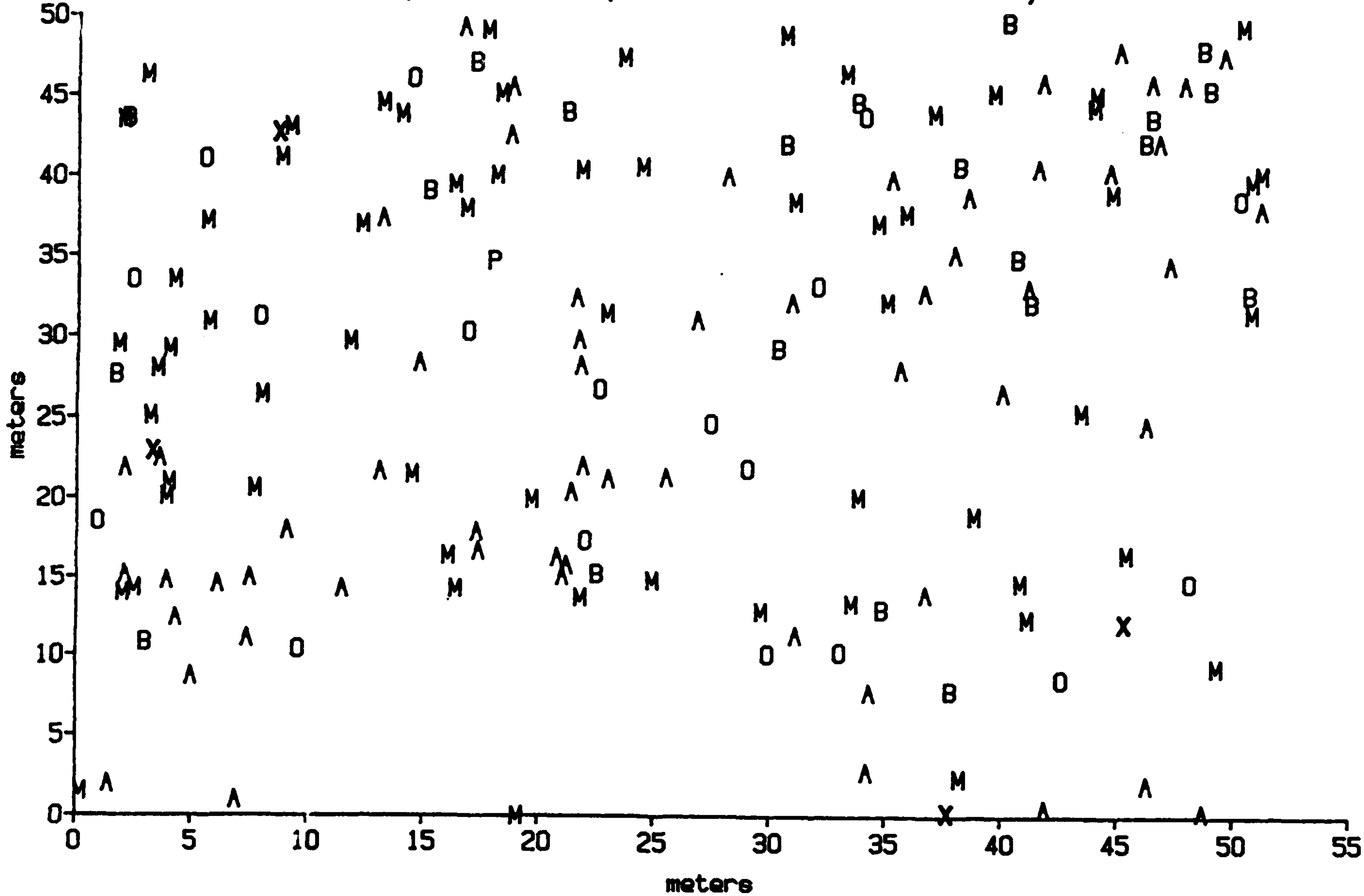


Figure 2

STUMPS AND ARMILLARIA MORTALITY SEEDLINGS

GROUND SITE (112) - AS OF DECEMBER 1987

Λ-Aspen O-Oak M-Maple B-Birch X-Mortality

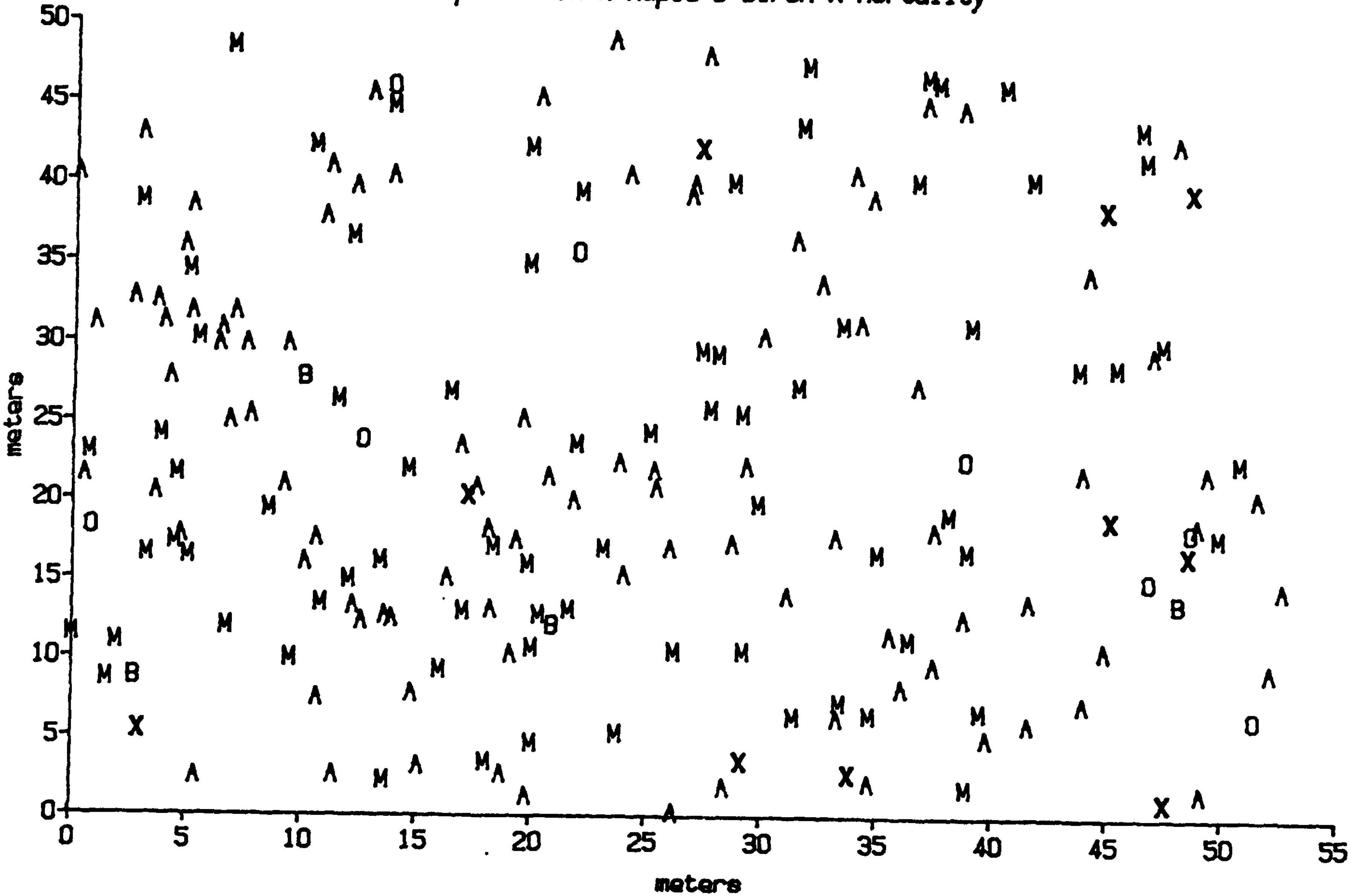


Figure 3

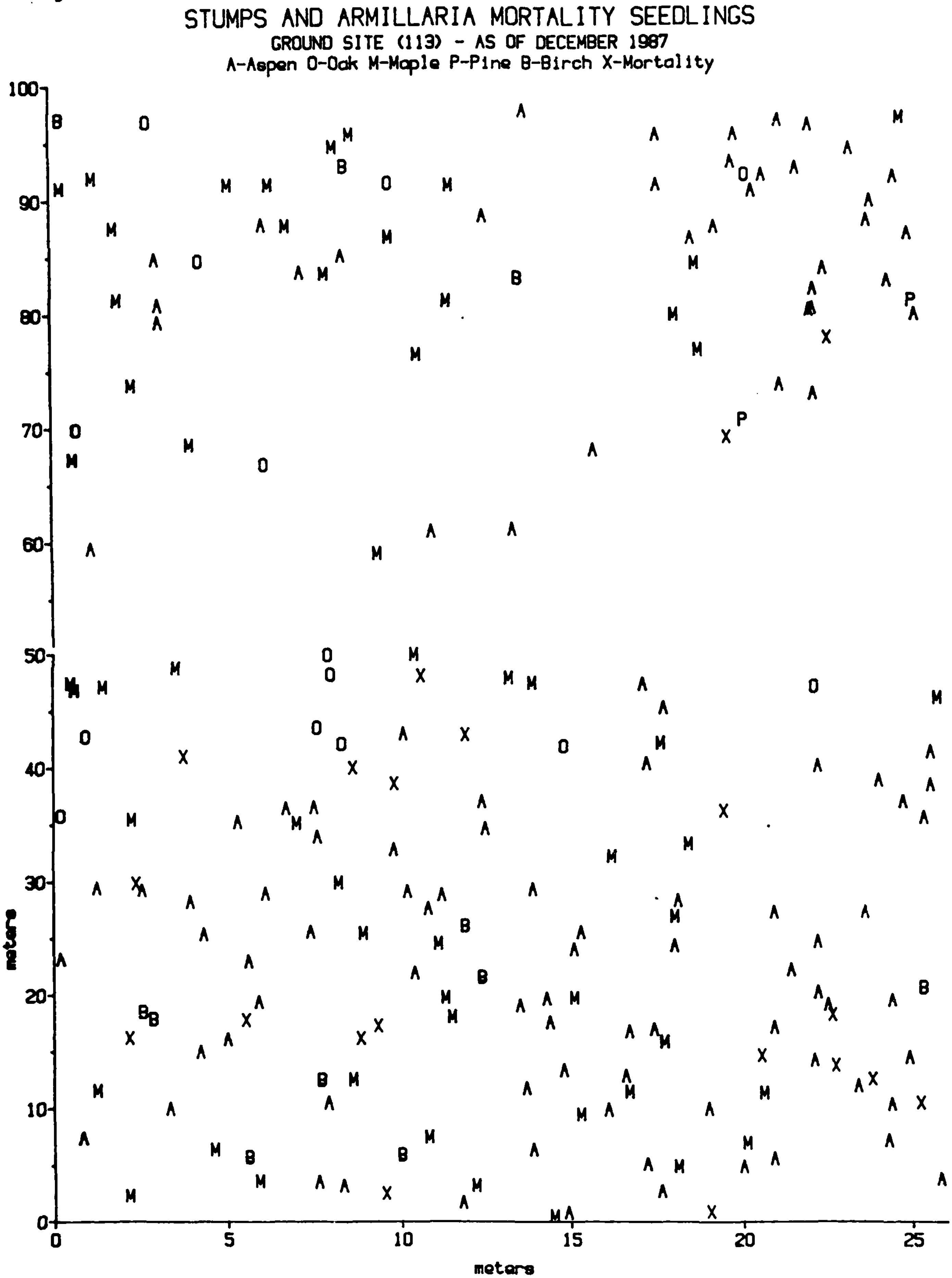

STUMPS AND ARMILLARIA MORTALITY SEEDLINGS
GROUND SITE (113) - AS OF DECEMBER 1987
A-Aspen O-Oak M-Maple P-Pine B-Birch X-Mortality
meters
meters

Figure 4

STUMPS AND ARMILLARIA MORTALITY SEEDLINGS

ANTENNA SITE (211) - AS OF DECEMBER 1987

A-Aspen O-Oak M-Maple P-Pine B-Birch X-Mortality

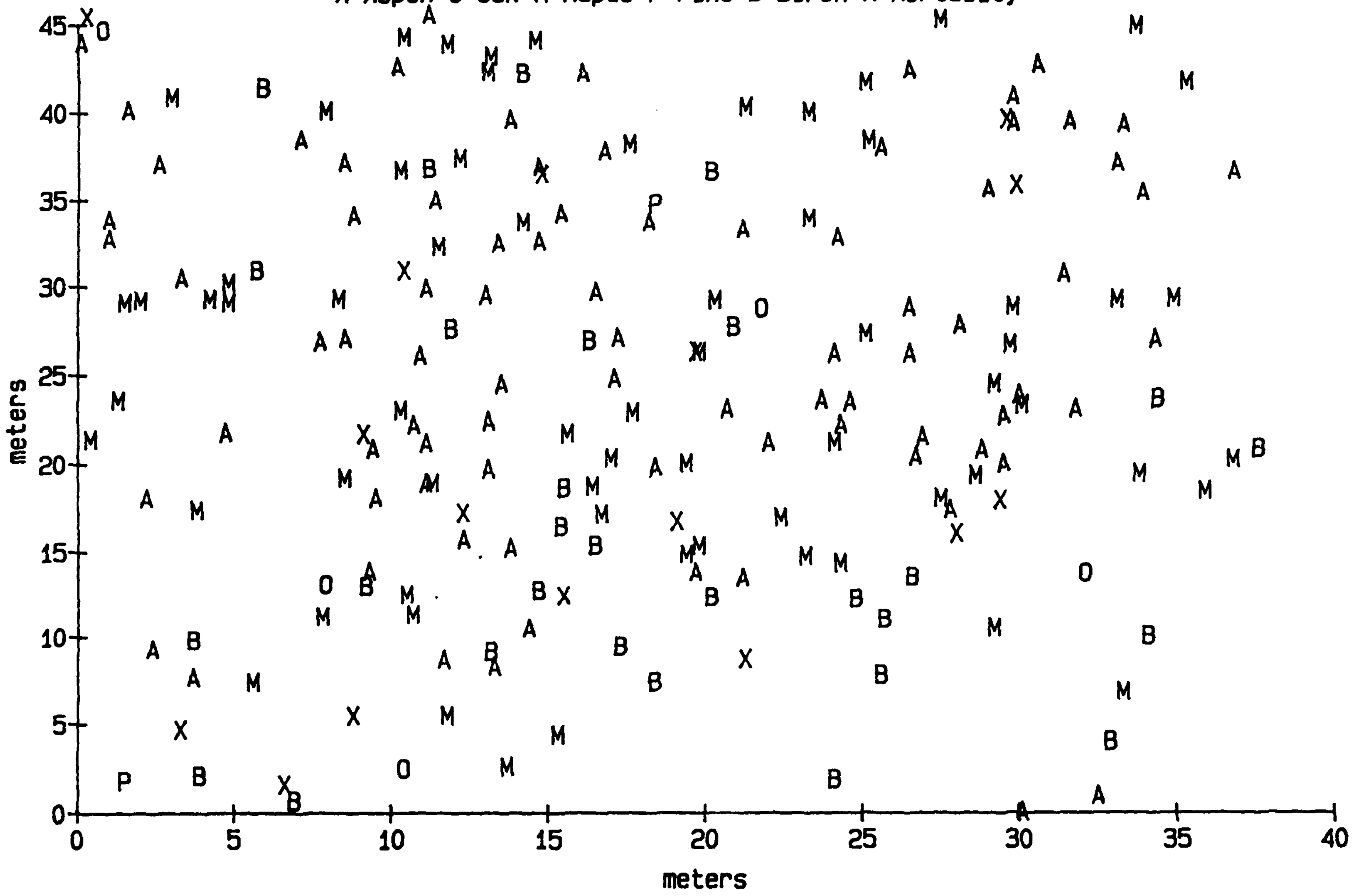


Figure 5

STUMPS AND ARMILLARIA MORTALITY SEEDLINGS
ANTENNA SITE (212) - AS OF DECEMBER 1987
A-Aspen O-Oak M-Maple P-Pine B-Birch X-Mortality

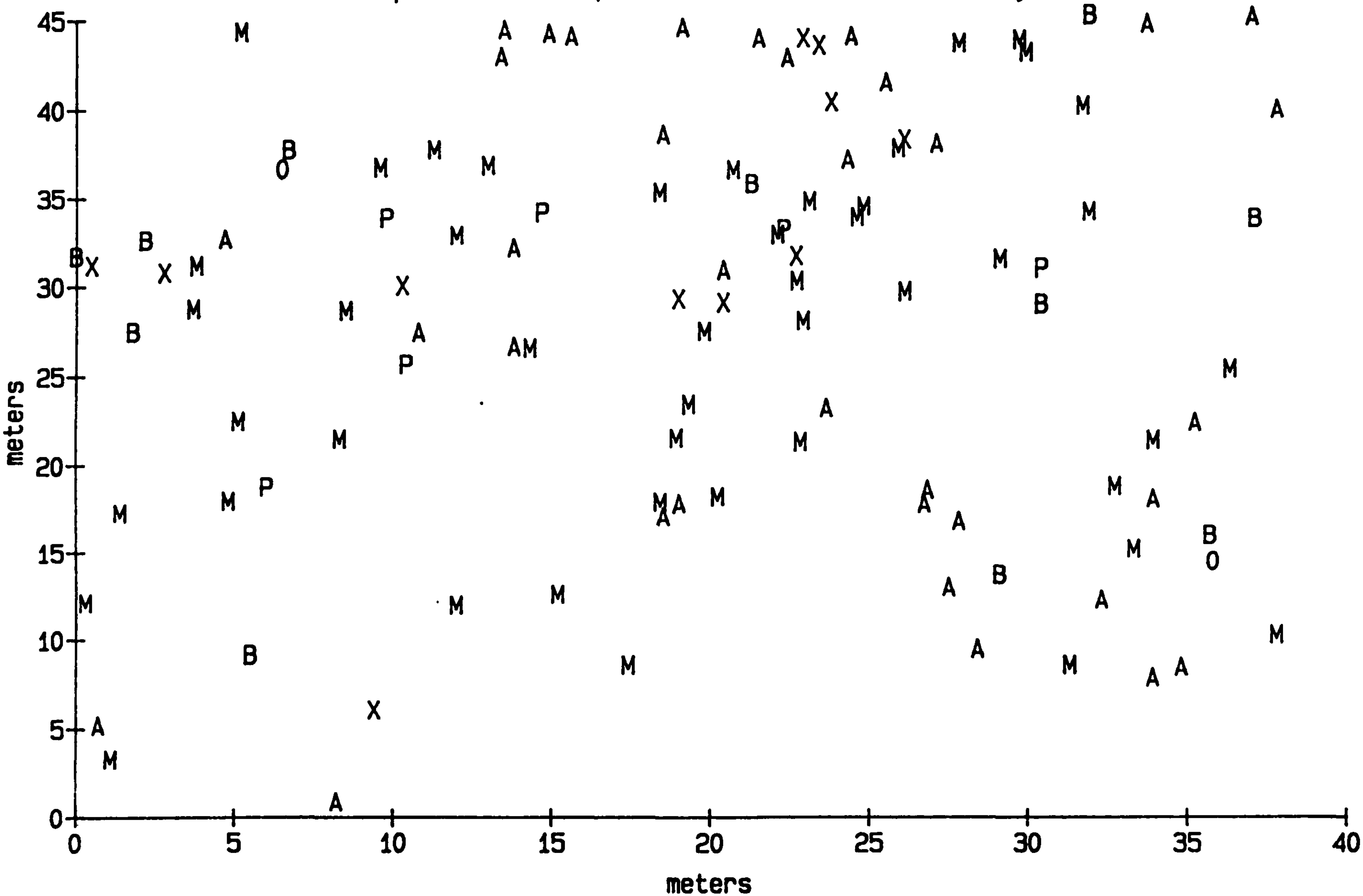


Figure 6

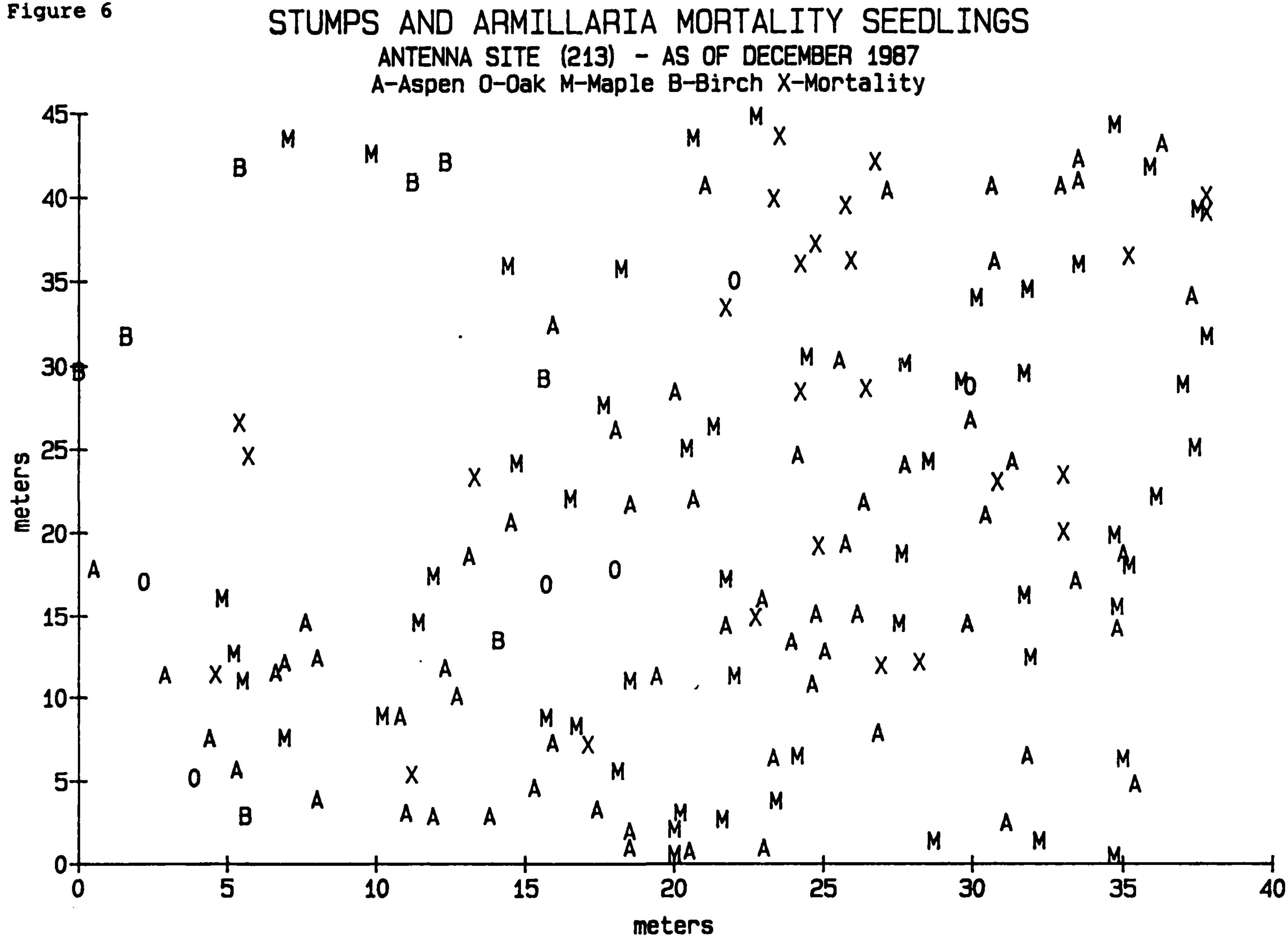

STUMPS AND ARMILLARIA MORTALITY SEEDLINGS
ANTENNA SITE (213) - AS OF DECEMBER 1987
A-Aspen O-Oak M-Maple B-Birch X-Mortality
meters
meters

Figure 7

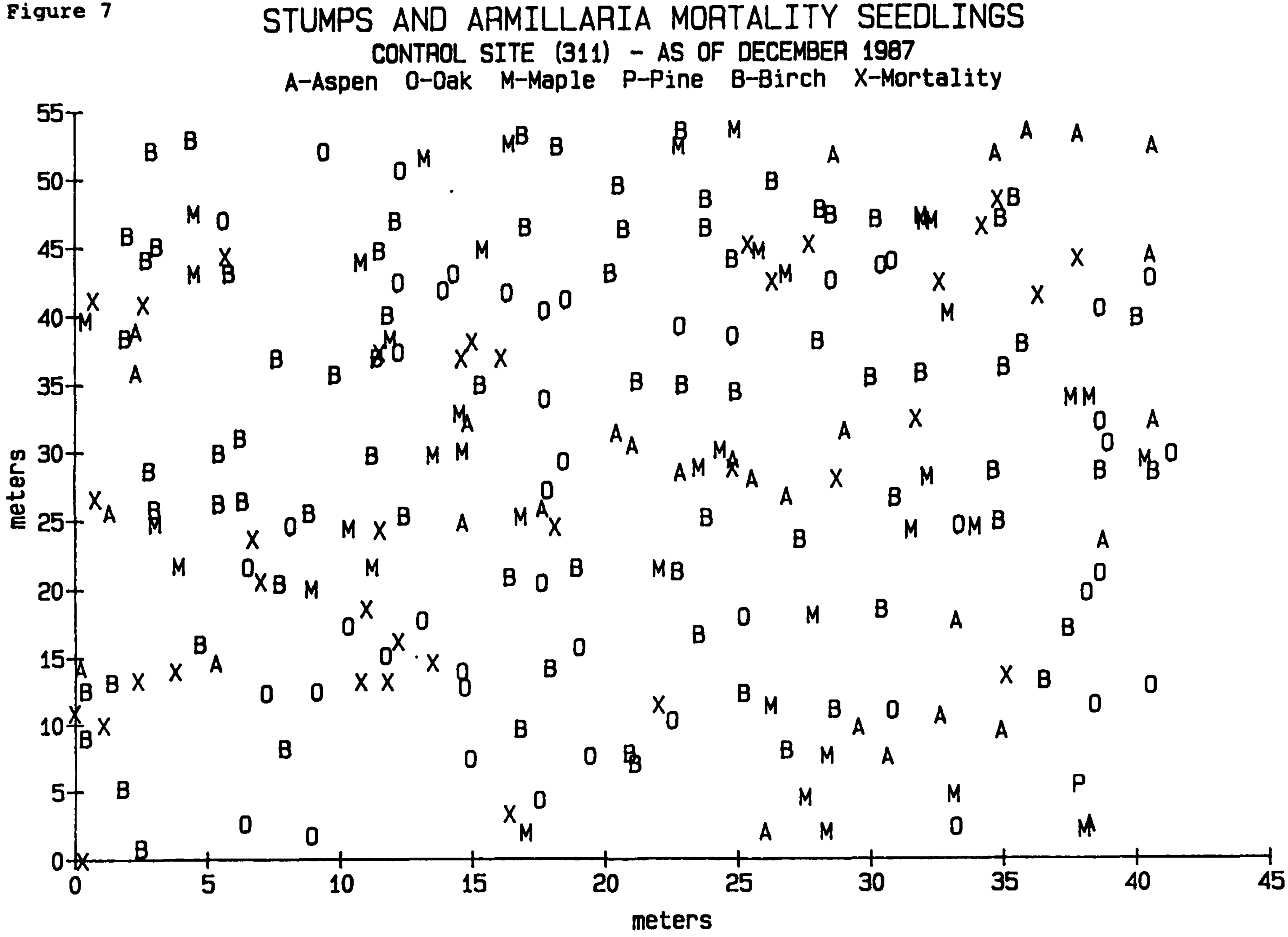

STUMPS AND ARMILLARIA MORTALITY SEEDLINGS
CONTROL SITE (311) - AS OF DECEMBER 1987
A-Aspen O-Oak M-Maple P-Pine B-Birch X-Mortality
meters
meters

Figure 8

STUMPS AND ARMILLARIA MORTALITY SEEDLINGS

CONTROL SITE (312) - AS OF DECEMBER 1987

A-Aspen O-Oak M-Maple B-Birch X-Mortality

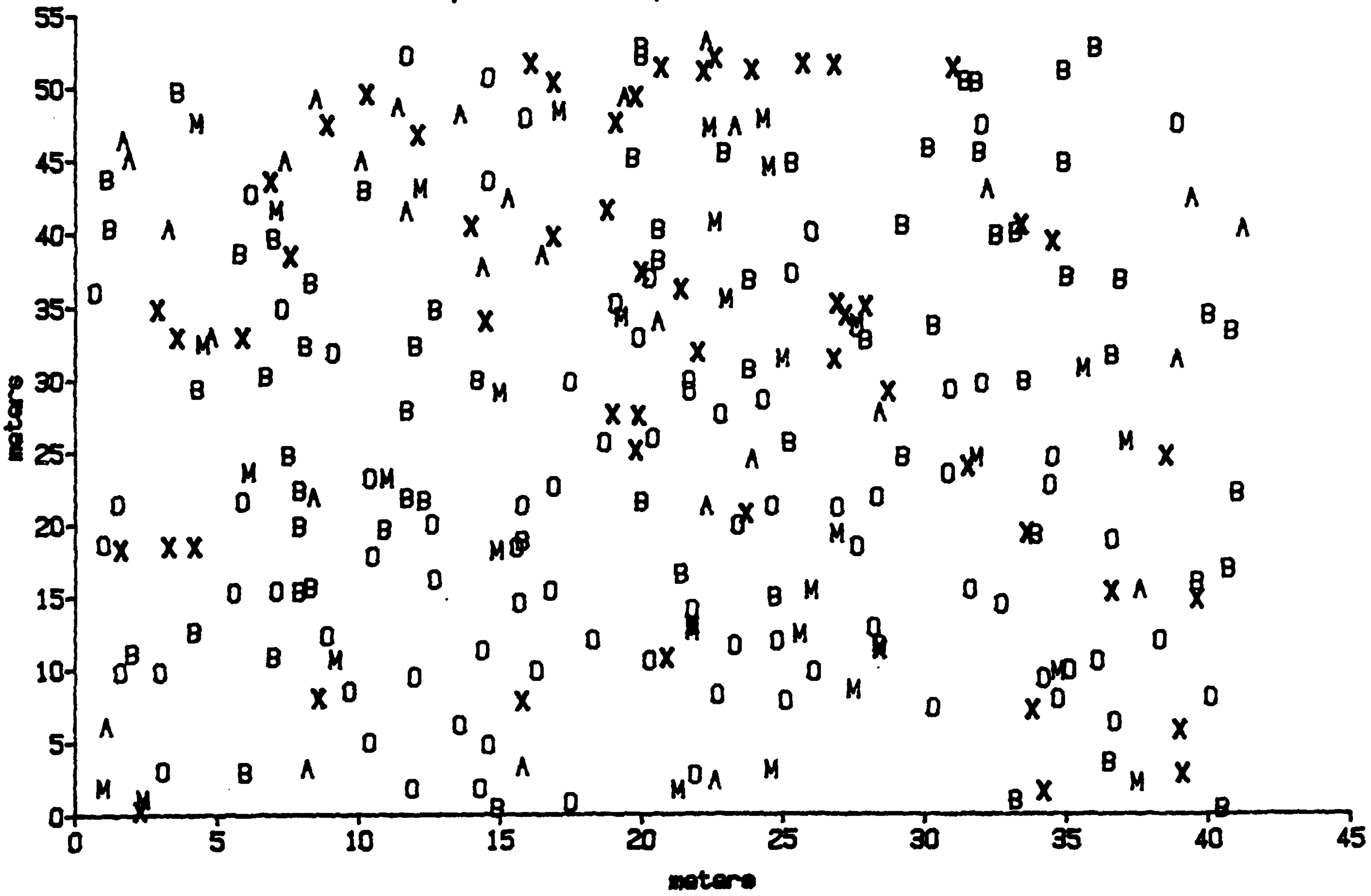
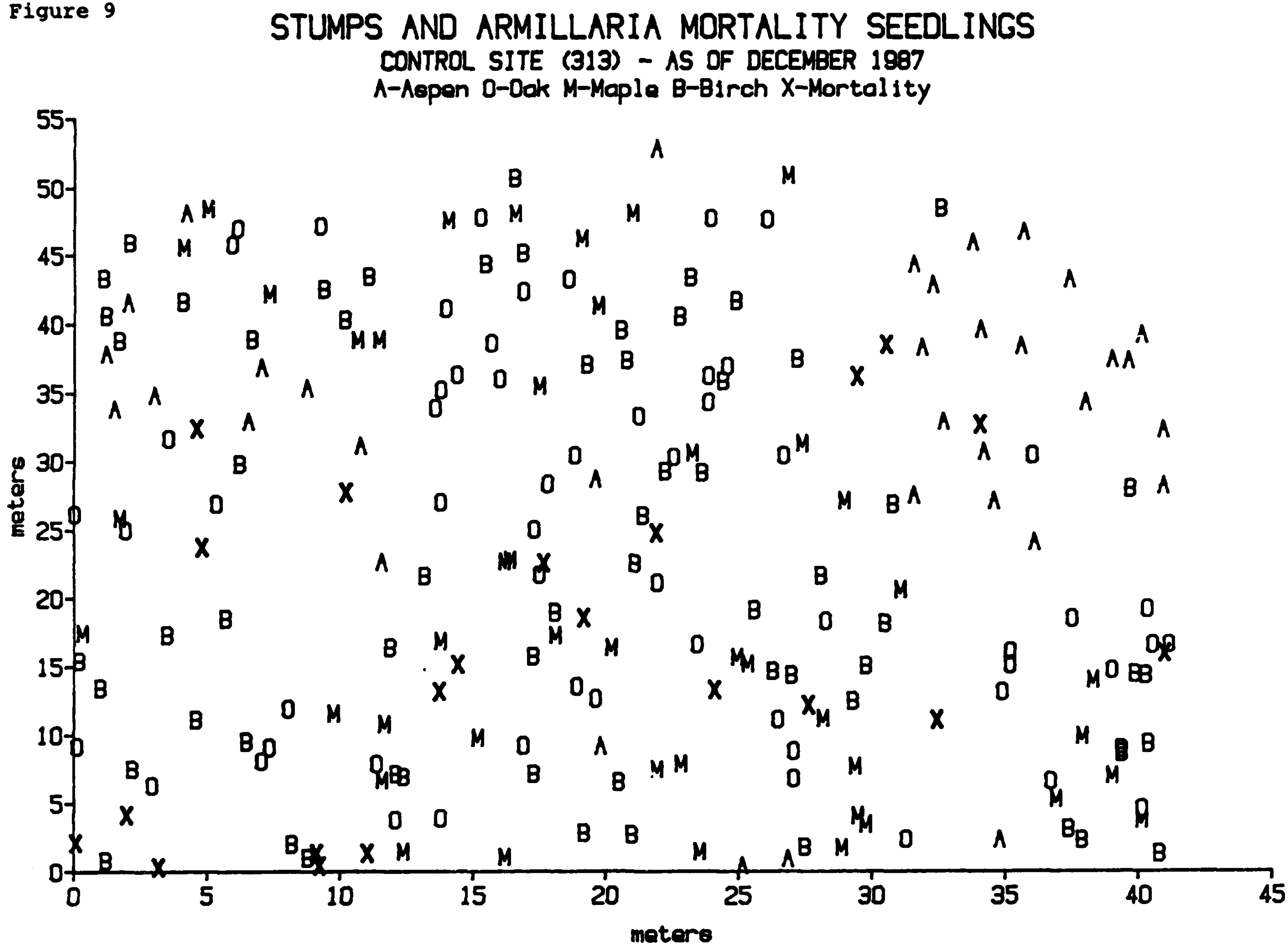
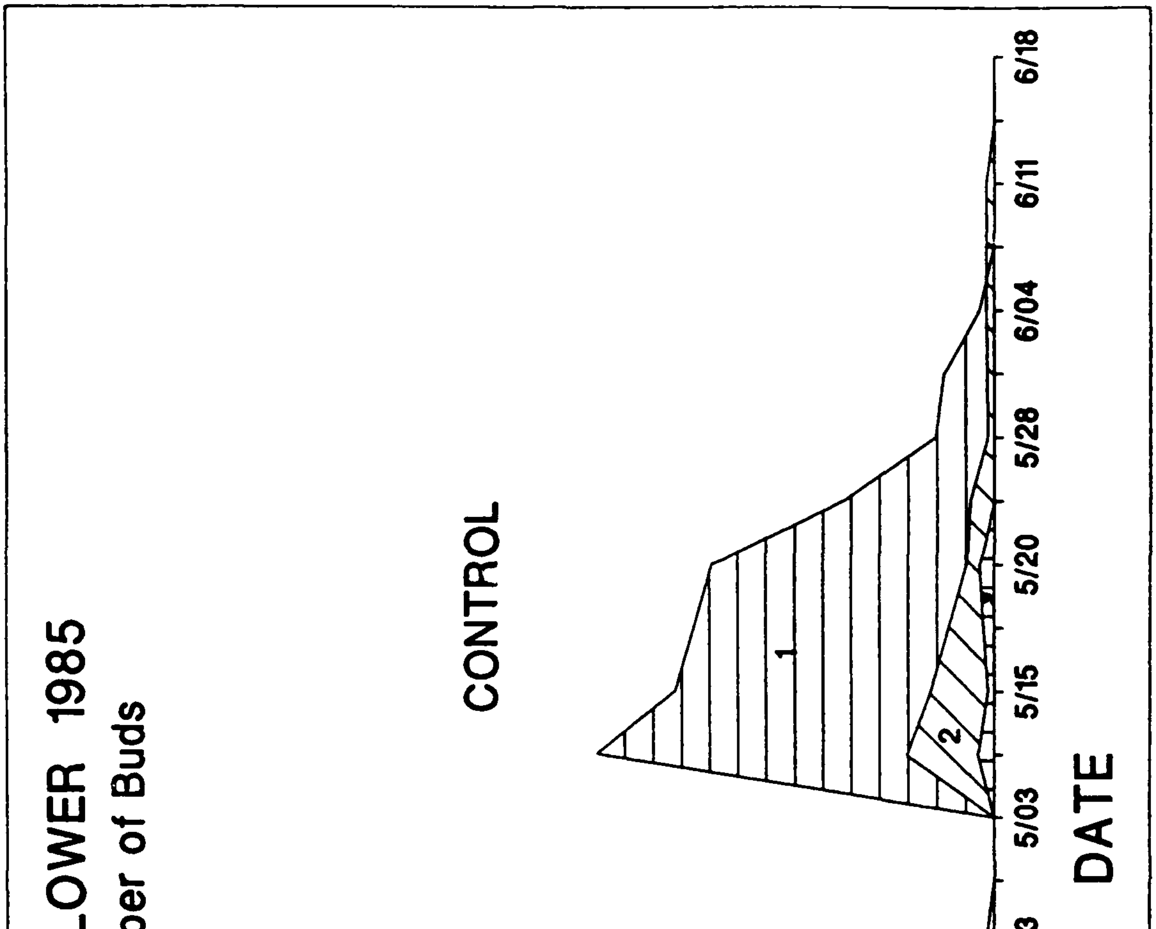


Figure 9


STUMPS AND ARMILLARIA MORTALITY SEEDLINGS
CONTROL SITE (313) - AS OF DECEMBER 1987
Λ-Aspen O-Oak M-Maple B-Birch X-Mortality
meters
meters

APPENDIX I

Figure 1



STARFLOWER 1985
Number of Buds
ANTENNA
CONTROL
RELATIVE FREQUENCY
0
10
20
30
40
50
5/03
5/14
5/24
5/31
6/06
6/13
5/03
5/15
5/20
5/28
6/04
6/11
6/18
DATE
1
2
3
1
2

Figure 2

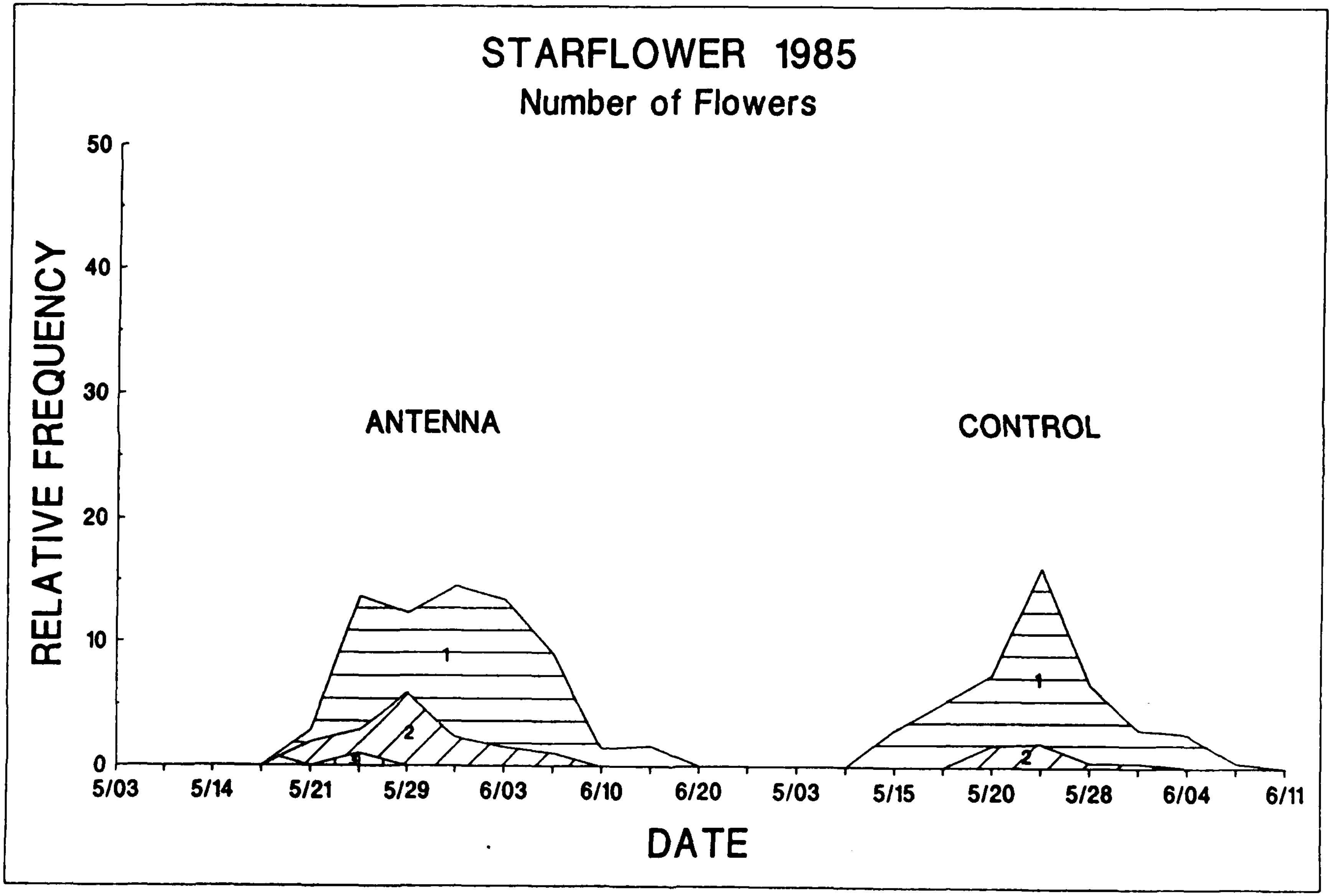
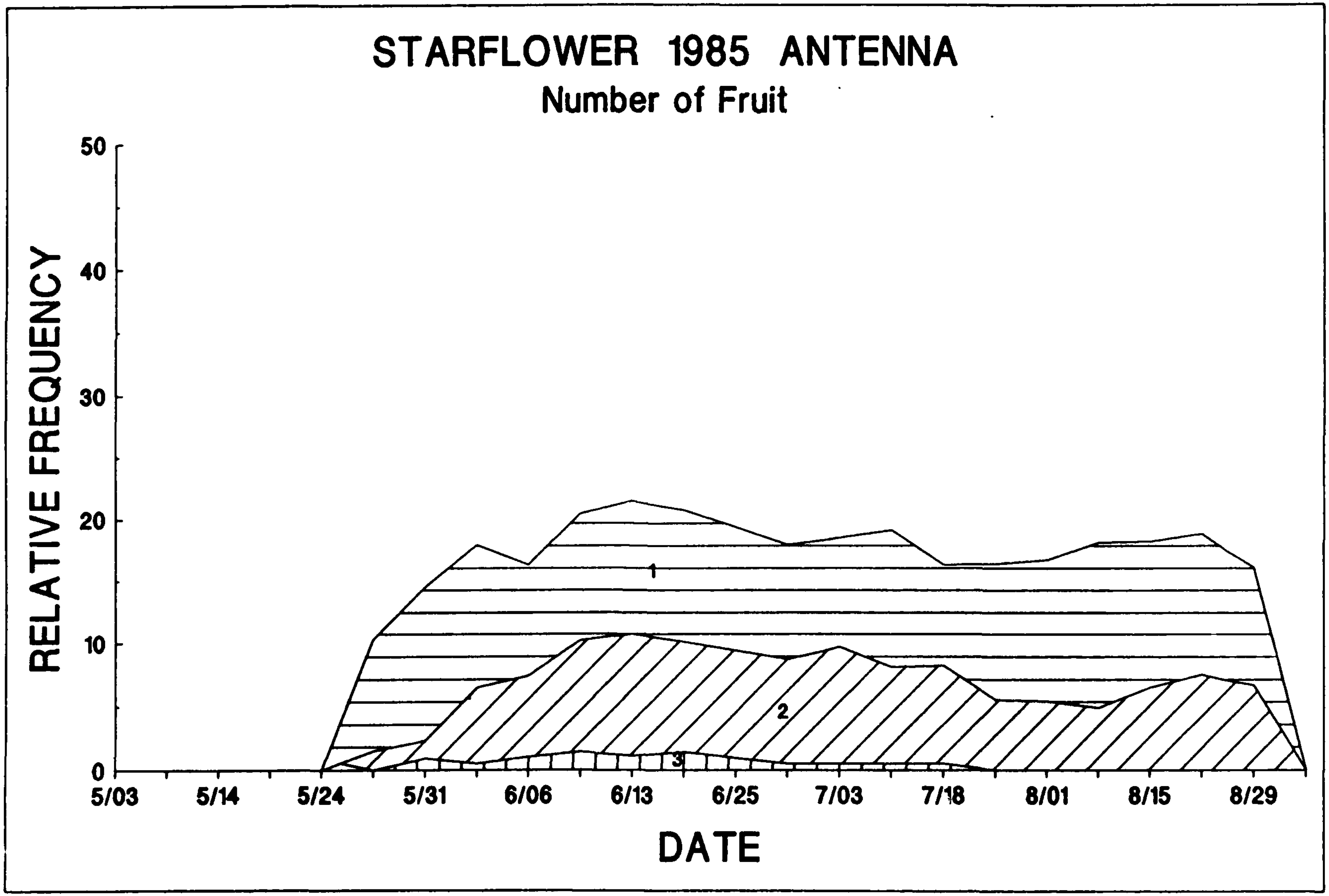

STARFLOWER 1985
Number of Flowers
RELATIVE FREQUENCY
50
40
30
20
10
0
ANTENNA
CONTROL
1
2
5/03
5/14
5/21
5/29
6/03
6/10
6/20
5/03
5/15
5/20
5/28
6/04
6/11
DATE

Figure 3



STARFLOWER 1985 ANTENNA
Number of Fruit
RELATIVE FREQUENCY
50
40
30
20
10
0
1
2
3
5/03
5/14
5/24
5/31
6/06
6/13
6/25
7/03
7/18
8/01
8/15
8/29
DATE

Figure 4

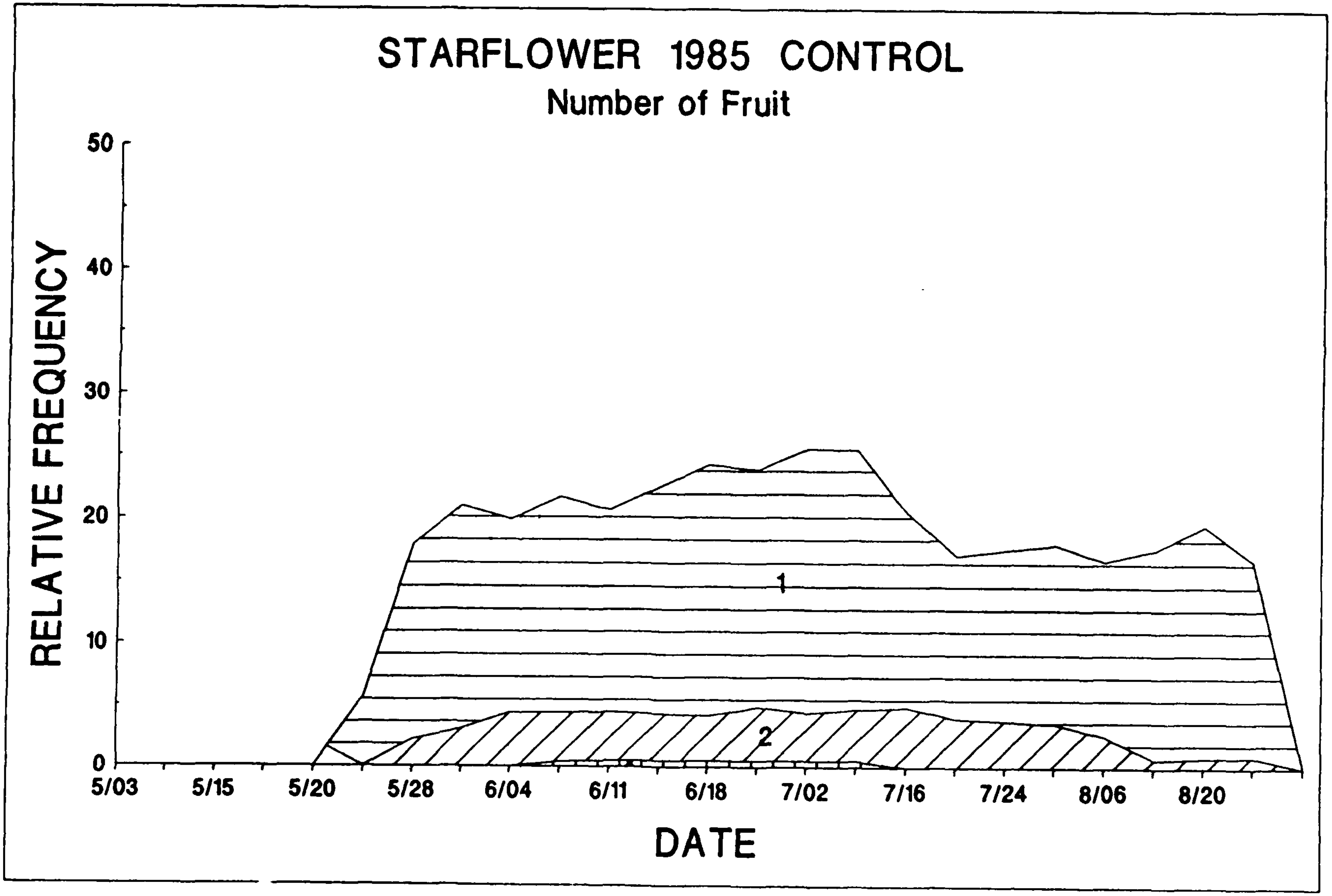
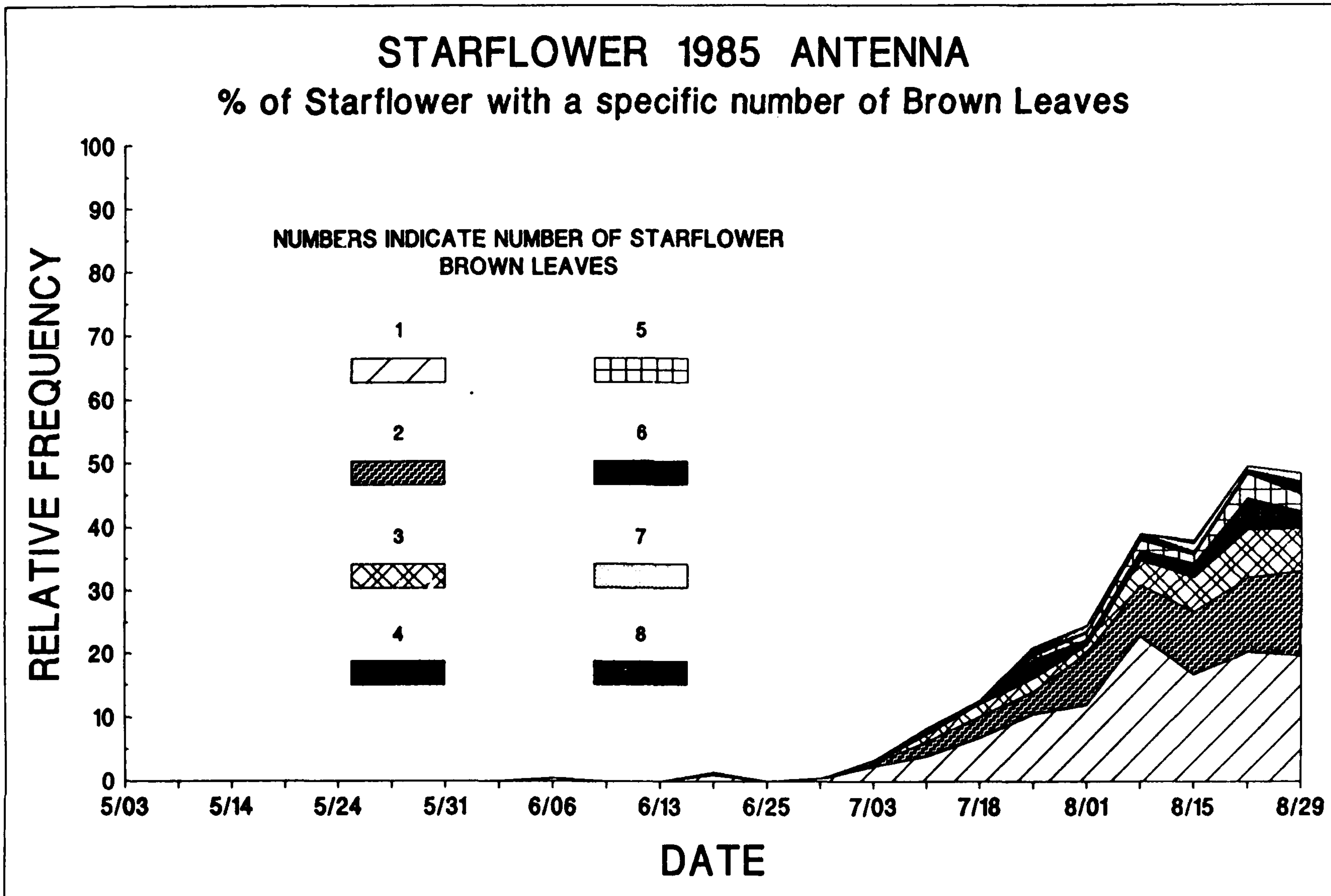

STARFLOWER 1985 CONTROL
Number of Fruit
RELATIVE FREQUENCY
50
40
30
20
10
0
1
2
5/03
5/15
5/20
5/28
6/04
6/11
6/18
7/02
7/16
7/24
8/06
8/20
DATE

Figure 5



STARFLOWER 1985 ANTENNA
% of Starflower with a specific number of Brown Leaves
RELATIVE FREQUENCY
100
90
80
70
60
50
40
30
20
10
0
NUMBERS INDICATE NUMBER OF STARFLOWER BROWN LEAVES
1
2
3
4
5
6
7
8
5/03
5/14
5/24
5/31
6/06
6/13
6/25
7/03
7/18
8/01
8/15
8/29
DATE

Figure 6

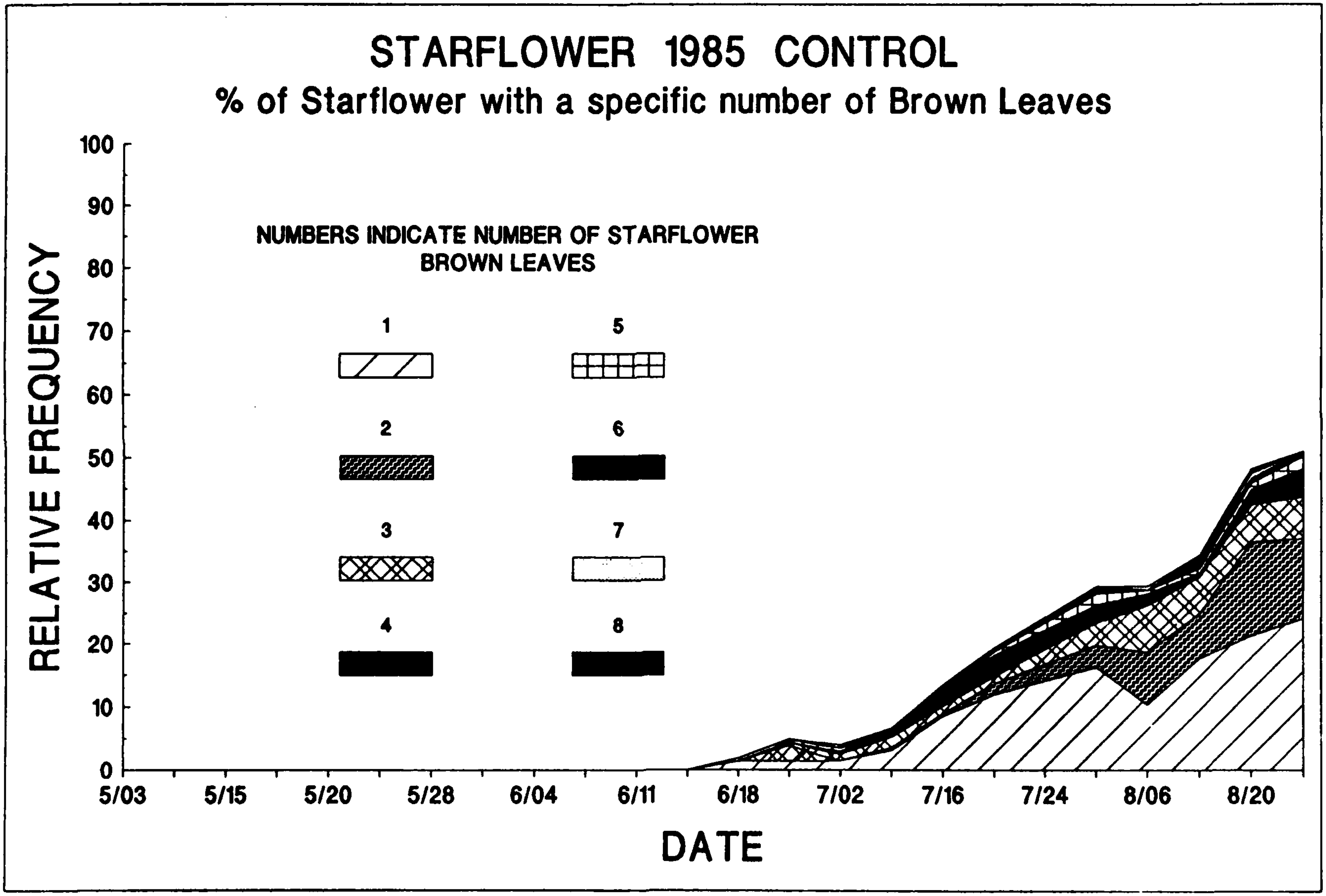
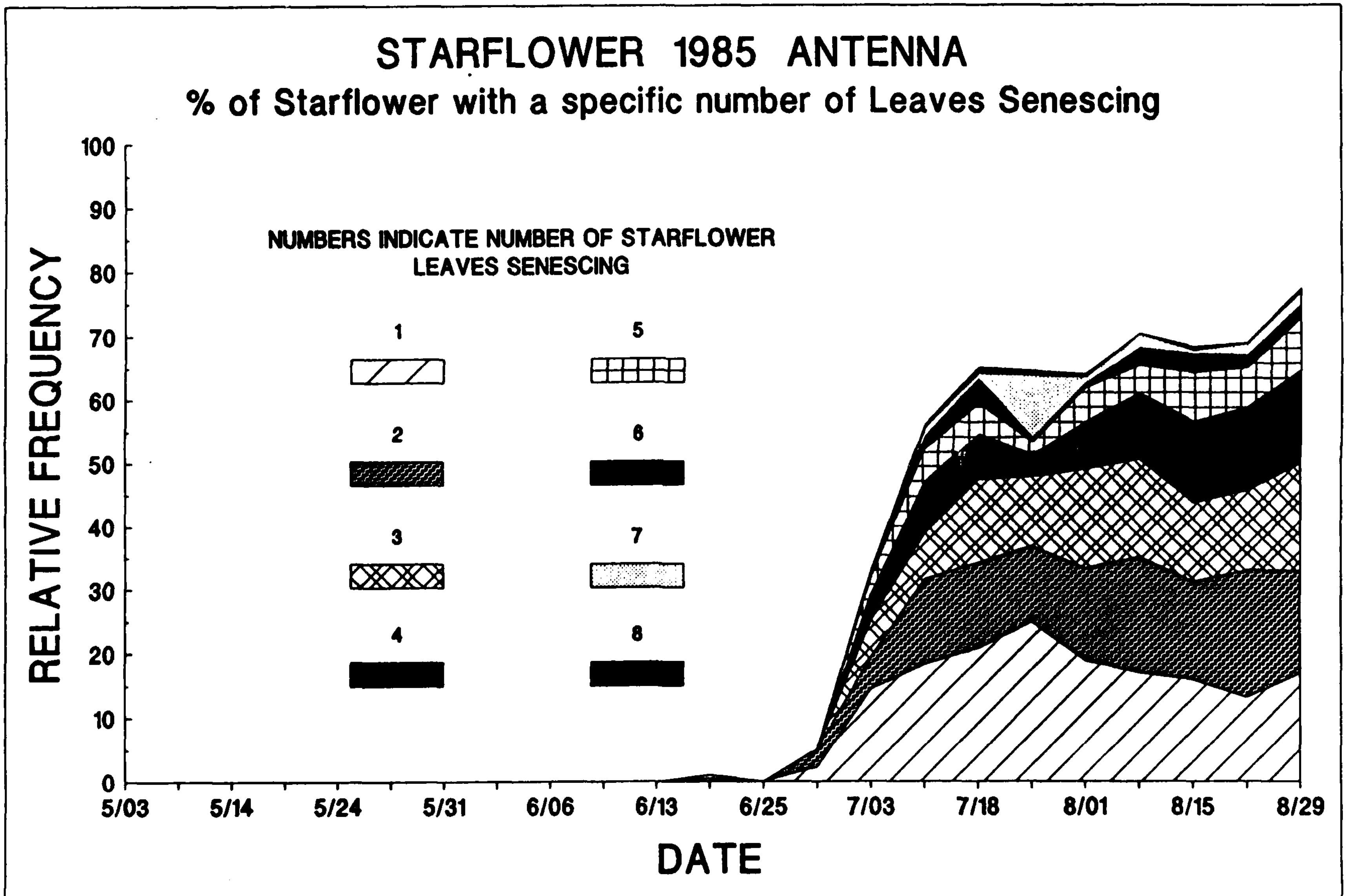
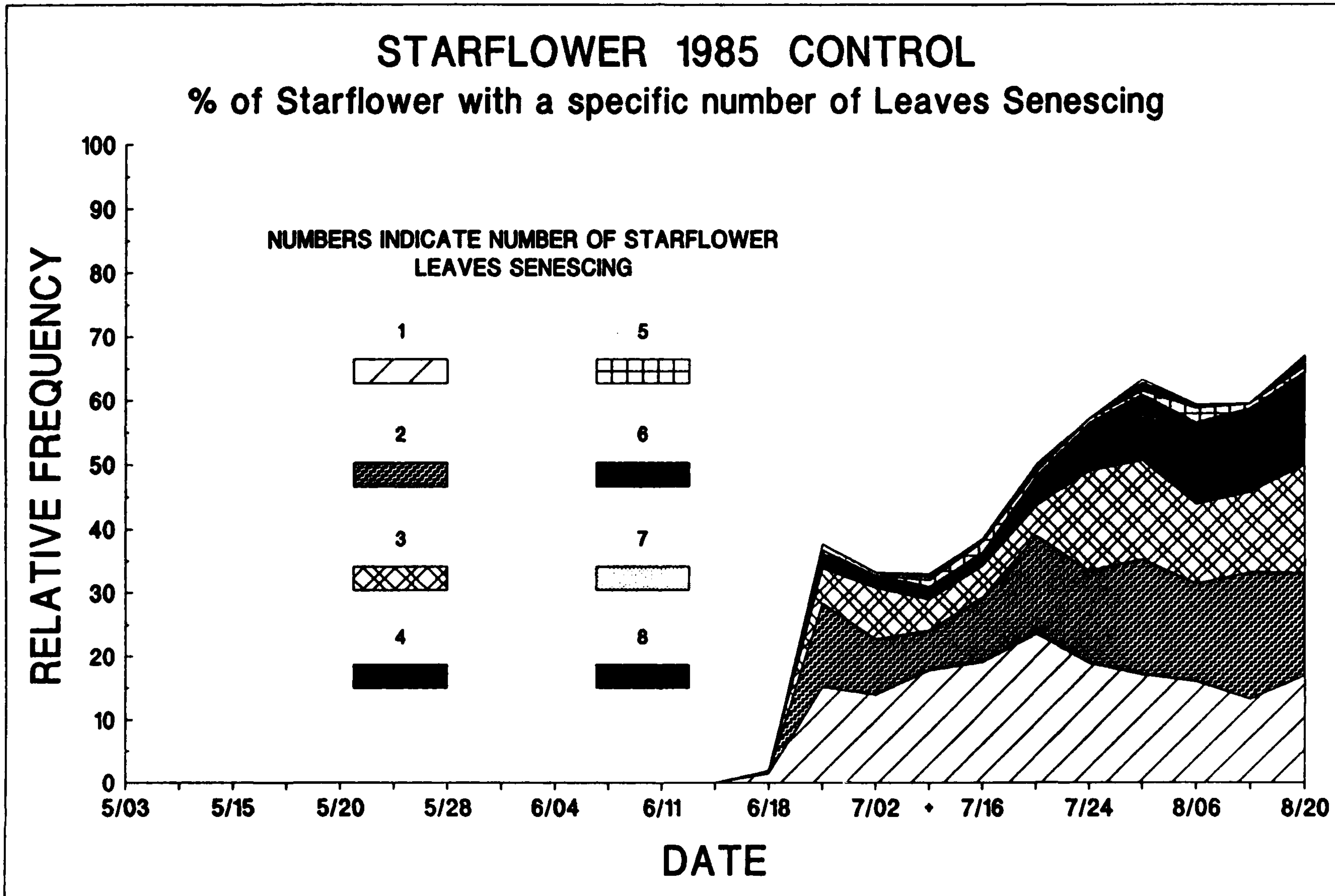

STARFLOWER 1985 CONTROL
% of Starflower with a specific number of Brown Leaves
RELATIVE FREQUENCY
100
90
80
70
60
50
40
30
20
10
0
NUMBERS INDICATE NUMBER OF STARFLOWER BROWN LEAVES
1
2
3
4
5
6
7
8
5/03
5/15
5/20
5/28
6/04
6/11
6/18
7/02
7/16
7/24
8/06
8/20
DATE

Figure 7



STARFLOWER 1985 ANTENNA
% of Starflower with a specific number of Leaves Senescing
RELATIVE FREQUENCY
100
90
80
70
60
50
40
30
20
10
0
NUMBERS INDICATE NUMBER OF STARFLOWER LEAVES SENESCING
1
2
3
4
5
6
7
8
5/03
5/14
5/24
5/31
6/06
6/13
6/25
7/03
7/18
8/01
8/15
8/29
DATE

Figure 8



STARFLOWER 1985 CONTROL
% of Starflower with a specific number of Leaves Senescing
RELATIVE FREQUENCY
100
90
80
70
60
50
40
30
20
10
0
NUMBERS INDICATE NUMBER OF STARFLOWER LEAVES SENESCING
1
2
3
4
5
6
7
8
5/03
5/15
5/20
5/28
6/04
6/11
6/18
7/02
7/16
7/24
8/06
8/20
DATE

Figure 9

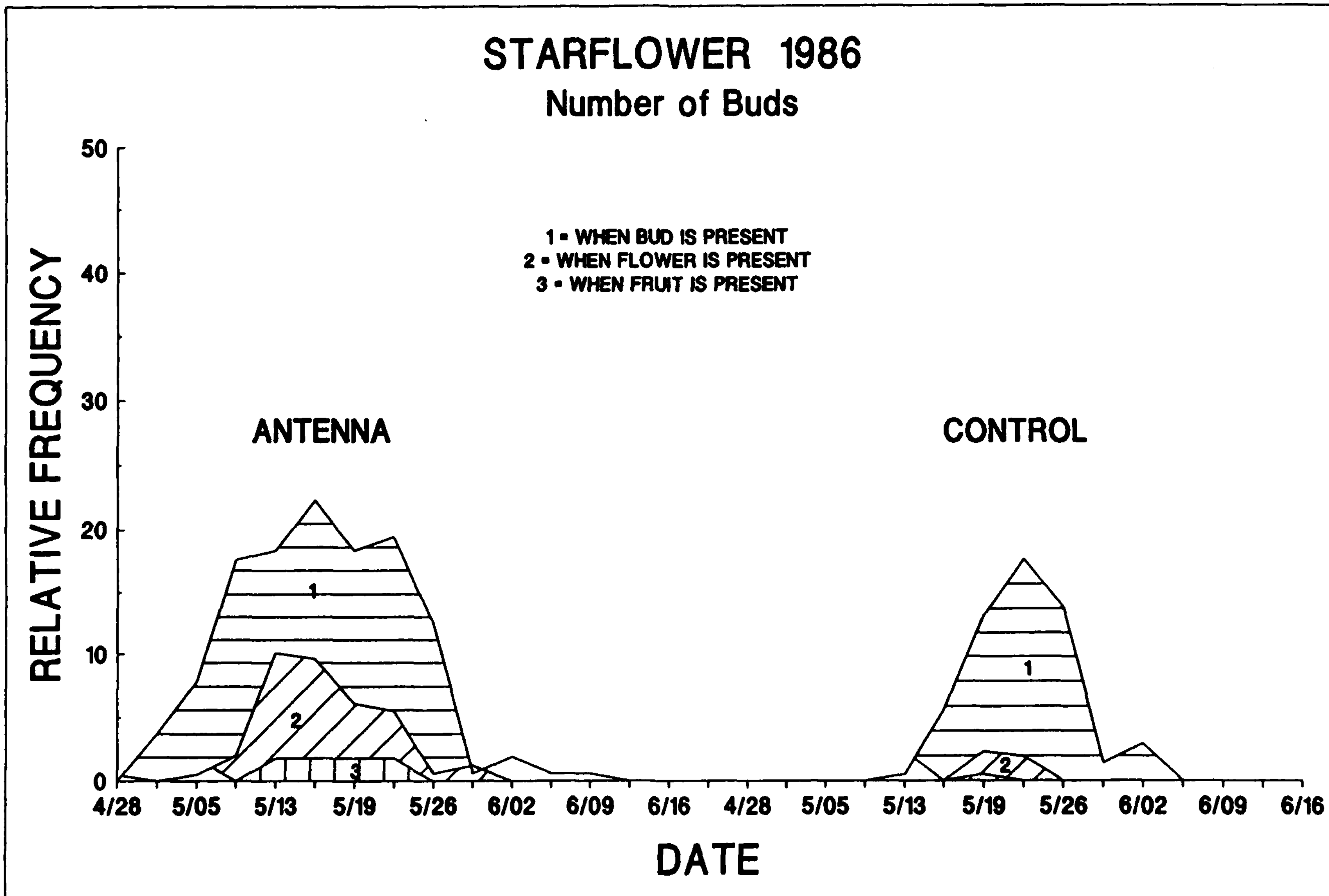
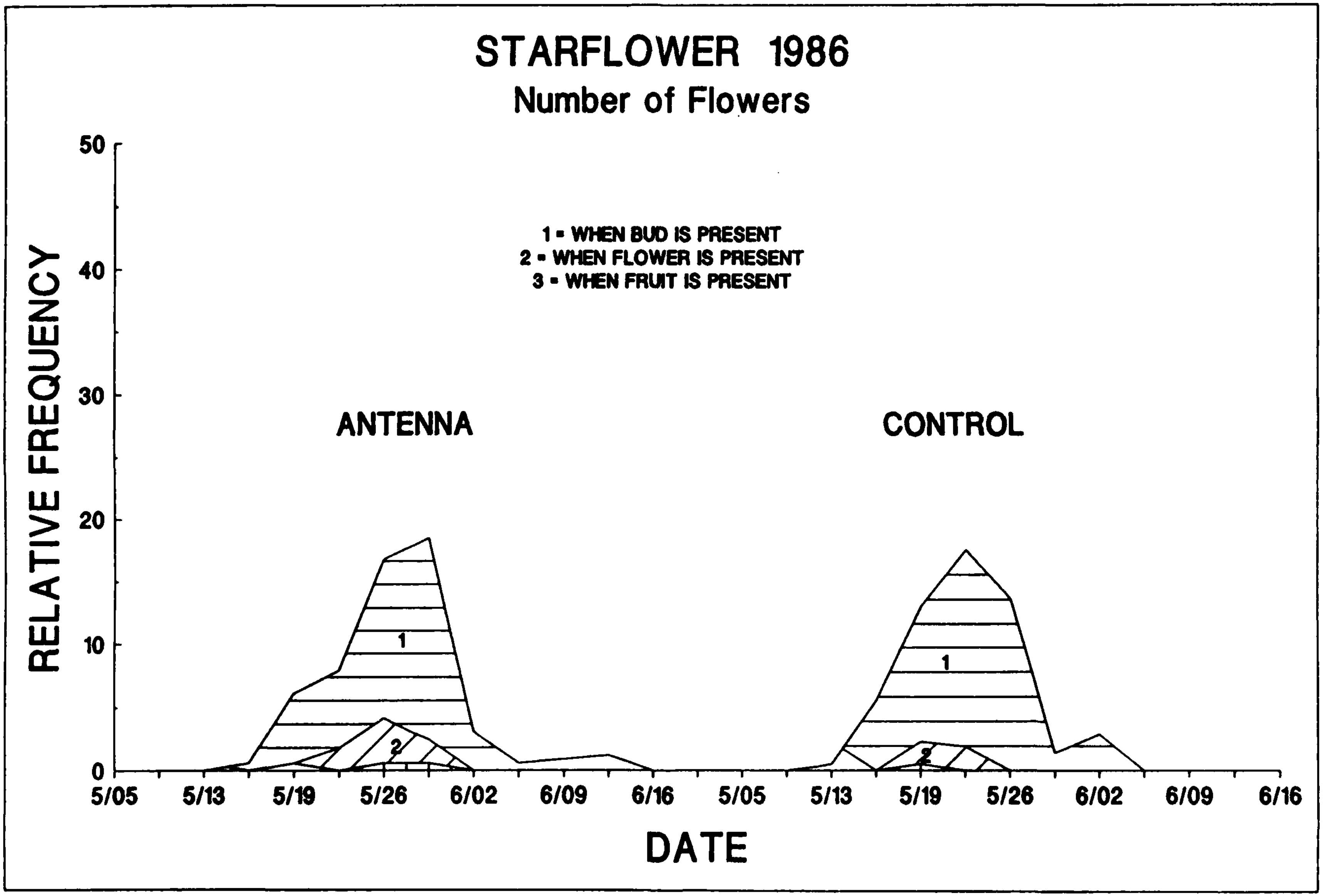
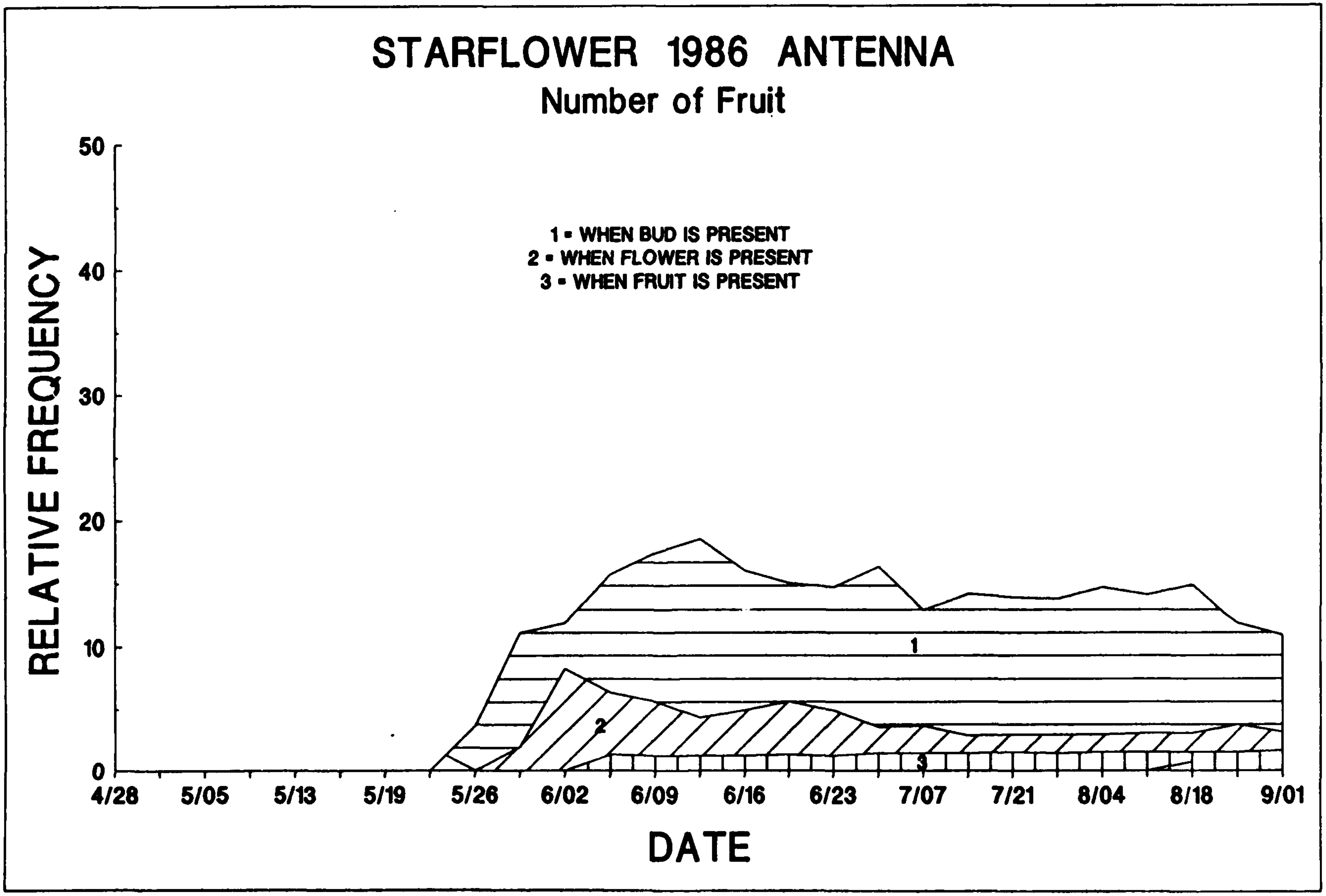

STARFLOWER 1986
Number of Buds
1 = WHEN BUD IS PRESENT
2 = WHEN FLOWER IS PRESENT
3 = WHEN FRUIT IS PRESENT
ANTENNA
CONTROL
RELATIVE FREQUENCY
0
10
20
30
40
50
4/28
5/05
5/13
5/19
5/26
6/02
6/09
6/16
4/28
5/05
5/13
5/19
5/26
6/02
6/09
6/16
DATE
1
2
3
1
2

Figure 10



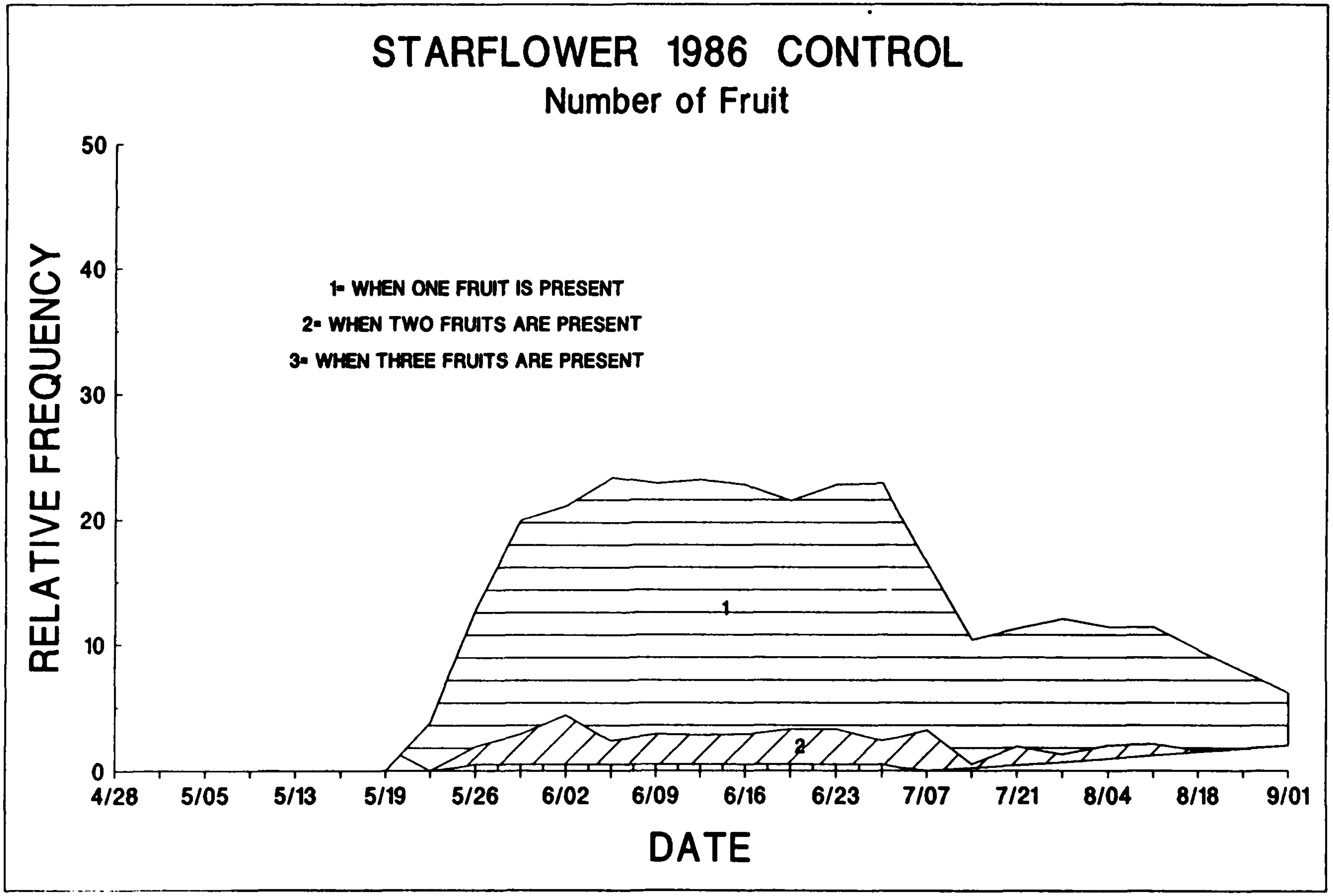
STARFLOWER 1986
Number of Flowers
1 = WHEN BUD IS PRESENT
2 = WHEN FLOWER IS PRESENT
3 = WHEN FRUIT IS PRESENT
ANTENNA
CONTROL
RELATIVE FREQUENCY
50
40
30
20
10
0
5/05
5/13
5/19
5/26
6/02
6/09
6/16
5/05
5/13
5/19
5/26
6/02
6/09
6/16
DATE
1
2
1
2

Figure 11



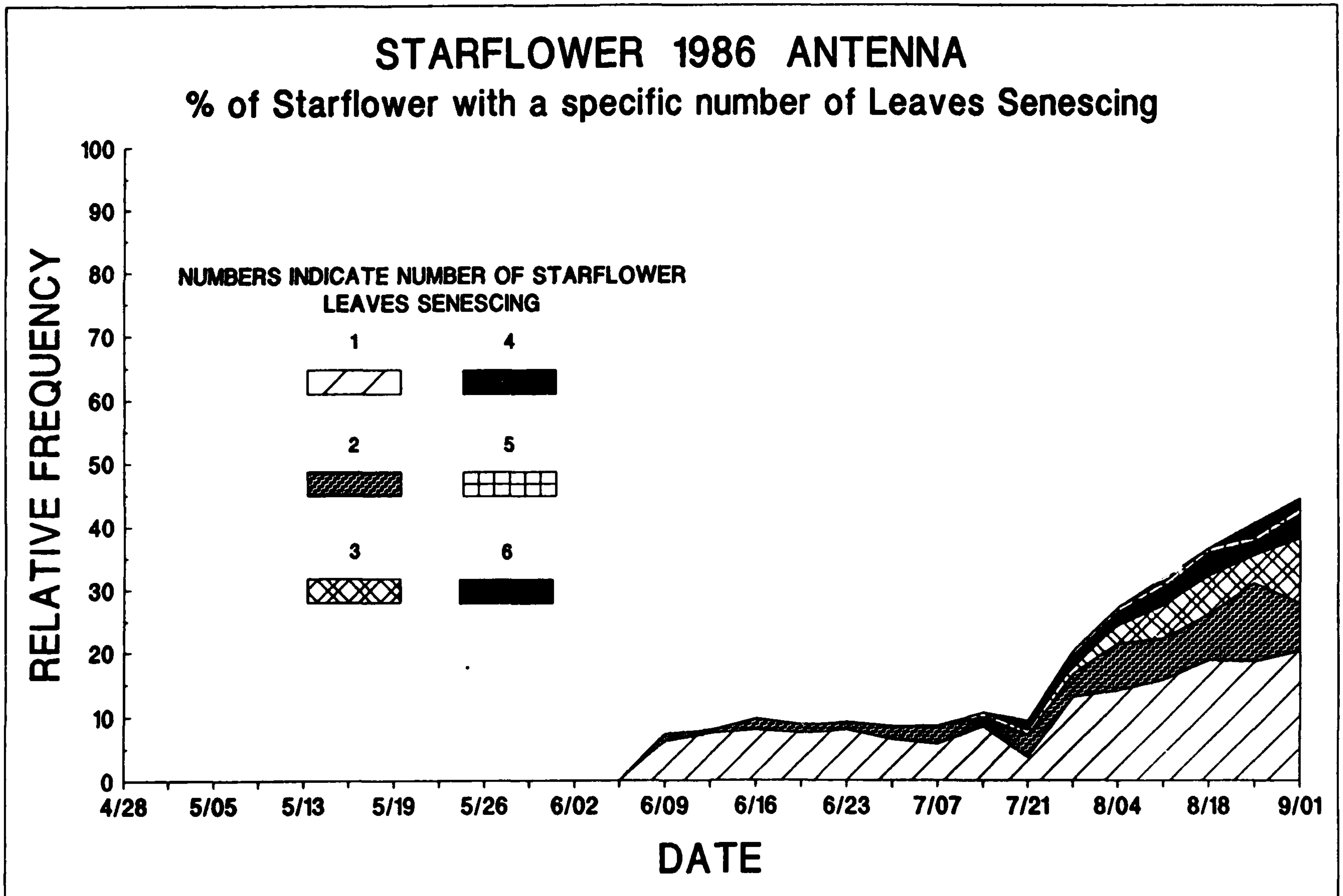
STARFLOWER 1986 ANTENNA
Number of Fruit
1 = WHEN BUD IS PRESENT
2 = WHEN FLOWER IS PRESENT
3 = WHEN FRUIT IS PRESENT
RELATIVE FREQUENCY
0
10
20
30
40
50
1
2
3
4/28
5/05
5/13
5/19
5/26
6/02
6/09
6/16
6/23
7/07
7/21
8/04
8/18
9/01
DATE

Figure 12



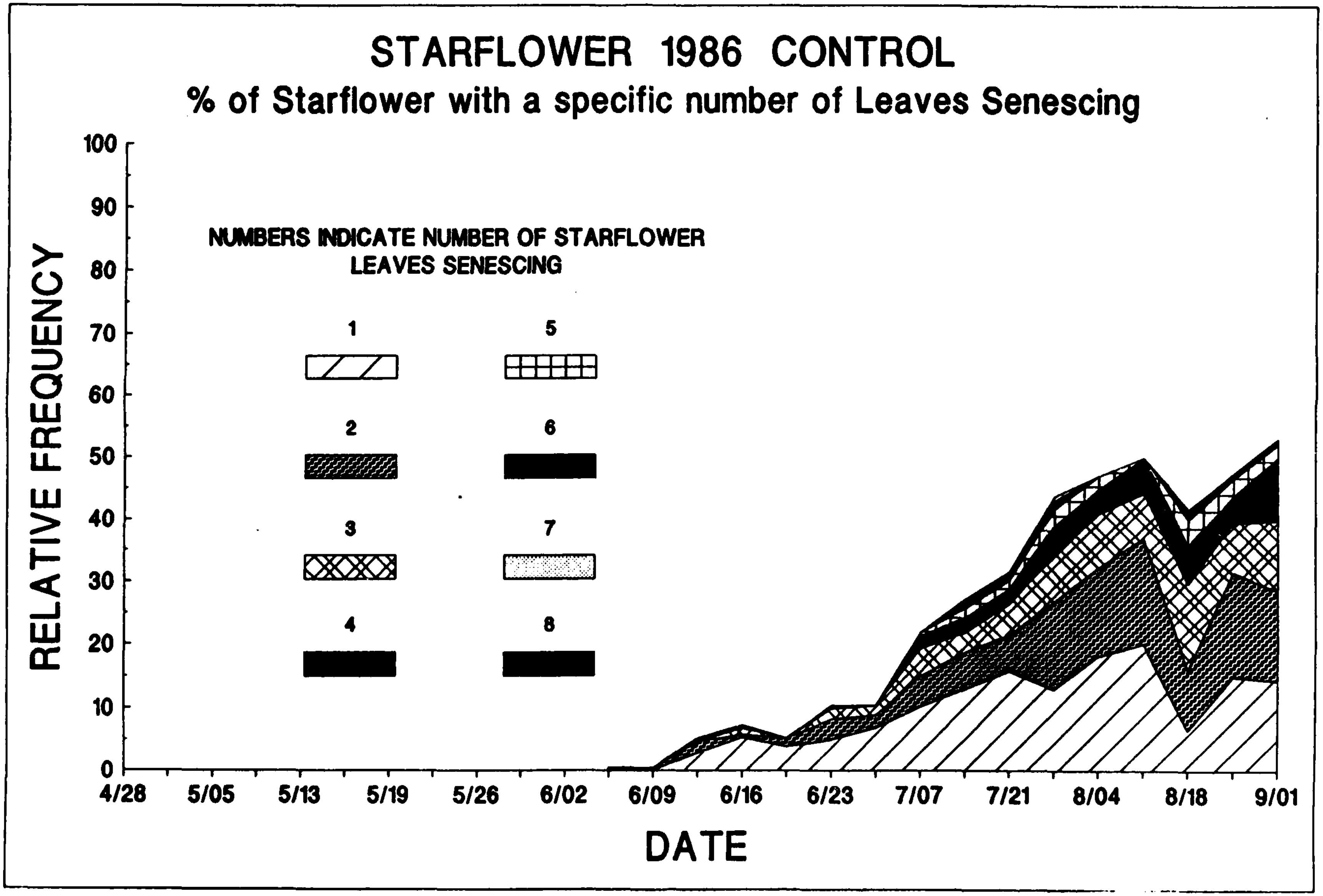
STARFLOWER 1986 CONTROL
Number of Fruit
RELATIVE FREQUENCY
50
40
30
20
10
0
1= WHEN ONE FRUIT IS PRESENT
2= WHEN TWO FRUITS ARE PRESENT
3= WHEN THREE FRUITS ARE PRESENT
1
2
4/28
5/05
5/13
5/19
5/26
6/02
6/09
6/16
6/23
7/07
7/21
8/04
8/18
9/01
DATE

Figure 13



STARFLOWER 1986 ANTENNA
% of Starflower with a specific number of Leaves Senescing
RELATIVE FREQUENCY
100
90
80
70
60
50
40
30
20
10
0
NUMBERS INDICATE NUMBER OF STARFLOWER LEAVES SENESCING
1
4
2
5
3
6
4/28
5/05
5/13
5/19
5/26
6/02
6/09
6/16
6/23
7/07
7/21
8/04
8/18
9/01
DATE

Figure 14



STARFLOWER 1986 CONTROL
% of Starflower with a specific number of Leaves Senescing
RELATIVE FREQUENCY
100
90
80
70
60
50
40
30
20
10
0
NUMBERS INDICATE NUMBER OF STARFLOWER LEAVES SENESCING
1
2
3
4
5
6
7
8
4/28
5/05
5/13
5/19
5/26
6/02
6/09
6/16
6/23
7/07
7/21
8/04
8/18
9/01
DATE

Figure 15

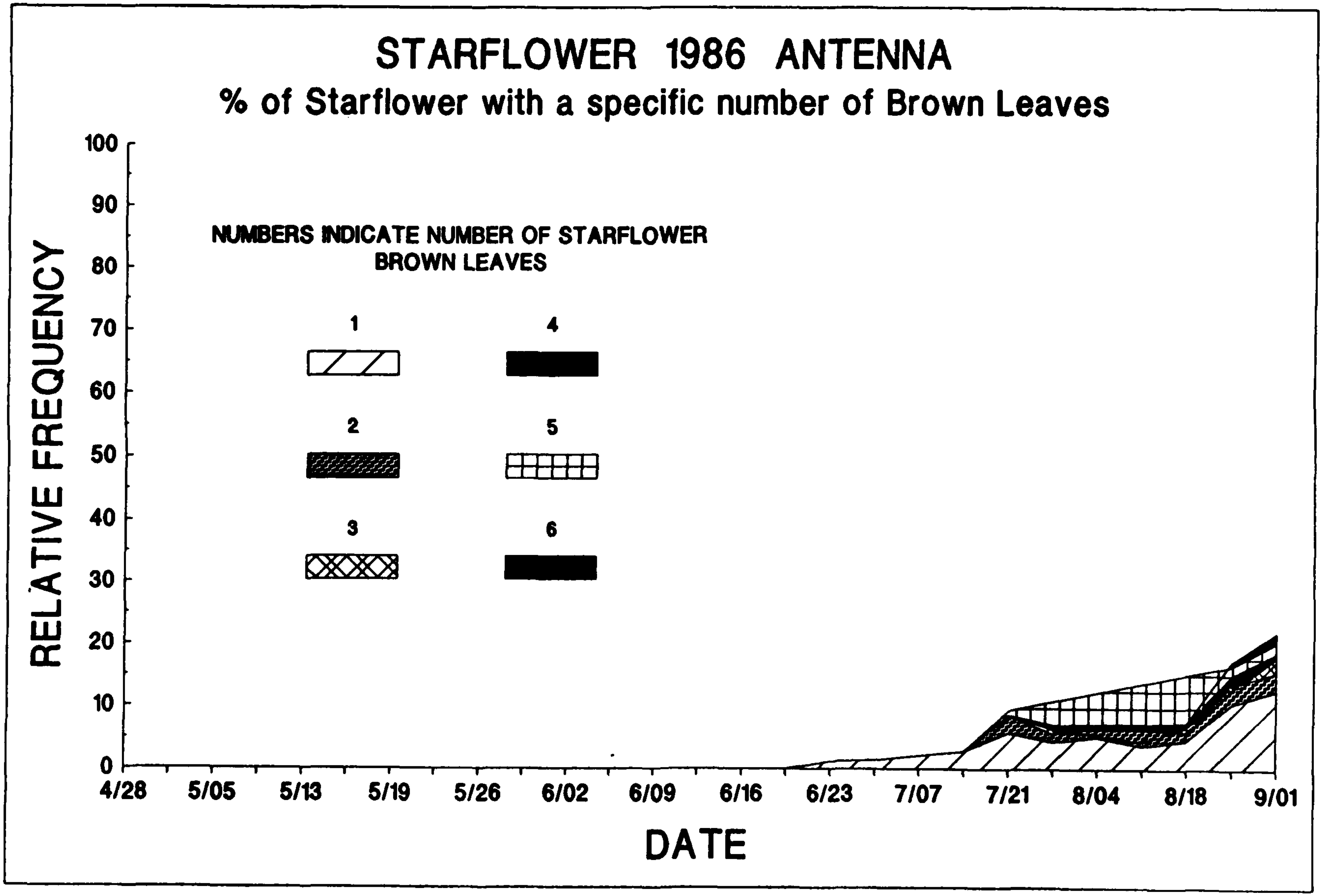
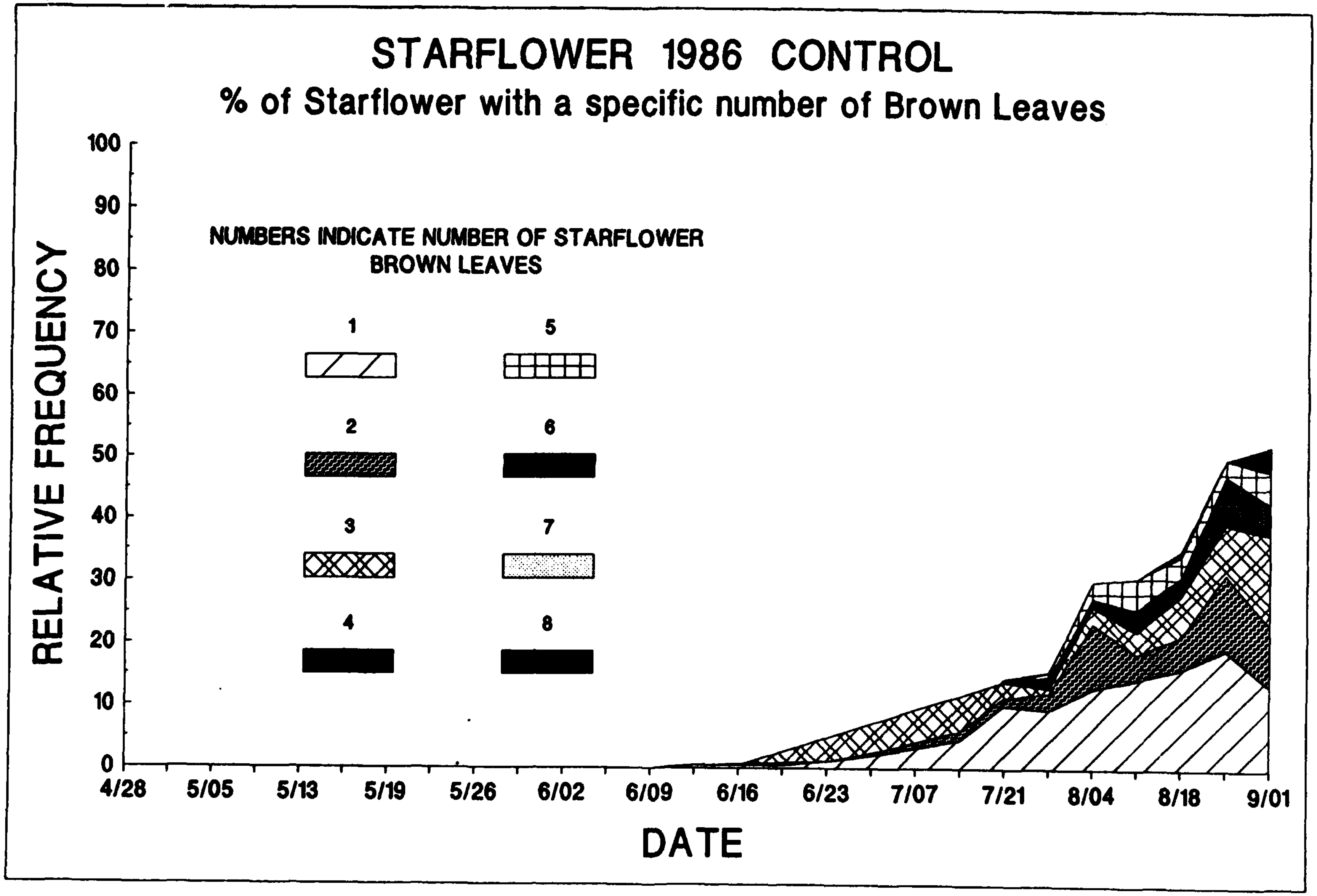

STARFLOWER 1986 ANTENNA
% of Starflower with a specific number of Brown Leaves
NUMBERS INDICATE NUMBER OF STARFLOWER BROWN LEAVES
1
2
3
4
5
6
RELATIVE FREQUENCY
0
10
20
30
40
50
60
70
80
90
100
4/28
5/05
5/13
5/19
5/26
6/02
6/09
6/16
6/23
7/07
7/21
8/04
8/18
9/01
DATE

Figure 16



STARFLOWER 1986 CONTROL
% of Starflower with a specific number of Brown Leaves
RELATIVE FREQUENCY
100
90
80
70
60
50
40
30
20
10
0
NUMBERS INDICATE NUMBER OF STARFLOWER BROWN LEAVES
1
2
3
4
5
6
7
8
4/28
5/05
5/13
5/19
5/26
6/02
6/09
6/16
6/23
7/07
7/21
8/04
8/18
9/01
DATE

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:
LITTER DECOMPOSITION AND MICROFLORA
The Michigan Study Site

ANNUAL REPORT, 1987

SUBCONTRACT NUMBER: E06549-84-C-002

MICHIGAN TECHNOLOGICAL UNIVERSITY
HOUGHTON, MICHIGAN

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:

LITTER DECOMPOSITION AND MICROFLORA

The Michigan Study Site

ANNUAL REPORT, 1987

SUBCONTRACT NUMBER: E06549-84-C-002

PROJECT MANAGER: Johann N. Bruhn

Johann N. Bruhn

Research Scientist

INVESTIGATORS: Johann N. Bruhn

Susan T. Bagley

James B. Pickens

RELEASING AUTHORITY: ______________________________

Secretary, Board of Control

MICHIGAN TECHNOLOGICAL UNIVERSITY

HOUGHTON, MICHIGAN

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SUMMARY

Litter Decomposition and Nutrient Flux

Three full years of experience with red pine, northern red oak, and red maple foliar litter decomposition have been completed on all three study units (including 2 hardwood stand and 3 plantation subunits). An additional year of useful data for red pine was collected in 1983-84 at the antenna hardwood stand subunit, and the samples for the fourth complete study have been installed in the field. The experimental sample units consist of 1) bagged bulk foliage samples of each litter species, for determination of both dry matter mass loss and associated nutrient flux, and 2) bagged individual fascicle/leaf samples, for more precise characterization of dry matter mass loss patterns. Dry matter mass loss data sets are complete at this time. Nutrient (N, P, K, Ca, and Mg) data sets for the 1983-84, 1984-85, and 1985-86 studies are complete, while bulk samples from the 1986-87 study are currently being ground for analysis.

The level of precision obtained in our studies with bulk and individual fascicle/leaf samples of each litter species is expressed for convenience as the minimum shift in each sample mean which would be detected (α = .05). As in the 1986 Annual Report, minimum detectable differences are presented in the summary tables for raw dry matter and nutrient mass loss data representing each sample type collected on each sampling date in 1987 at each field subunit. In this report, minimum detectable differences are also reported for treatment means (years, monthly sampling dates, and plantation or hardwood stand subunits) associated with selected analyses of variance (ANOVA) or covariance (ANACOV). Precision in the raw data sets has generally been highest in the hardwood stand subunits. Among the three study species, pine has provided the most precise information, while maple (and filter paper disk) data are much less precise. Maple was replaced by Whatman Number 1 filter paper disks as a possible alternative individual leaf study species in the 1986-87 study.

The initial uniformity of the disks was perceived to be a major advantage over the much more heterogeneous maple leaf population. Unfortunately, the deterioration of filter paper disks in the field proved to be highly variable. Neither individual maple leaves nor filter paper disks are included in the 1987-88 study.

Dry matter mass loss data have been transformed to the arc sin square root of X (where X is the proportion of original mass remaining) to homogenize variances prior to ANOVA or ANACOV. Three-way ANOVA, for detection of differences among years, monthly sampling dates, and plantation or hardwood stand subunits found that bulk samples of all three litter species on both types of subunit decomposed at least as fast in 1985 as in 1986 or 1987, and generally faster. Individual fascicles/leaves of all three species also decomposed at least as fast during 1985 as during 1986 or 1987 in the hardwood stands. Significant monthly progress in mass loss during May through October has been the rule in the plantation subunits, whereas significant monthly progress is often lacking at either end of the season in the hardwood stands. A variety of significant differences were detected among both types of subunit using ANOVA. Many of the significant differences among years, sampling dates, and subunits are attributable to very low variability within the data sets, as indicated by the minimum detectable differences reported. These differences do not appear to be consequential as well. This issue is discussed directly in the section of this report entitled Statistical Design.

Correlation analysis revealed strong relationships between transformed mass loss and 1) several temperature- and moisture-related weather variables, 2) initial leaf density for oak and maple, and 3) percent nutrient content (N, P, Ca, and Mg) of retrieved bulk litter samples. Seasonal running totals of air and soil temperature degree days, frequency of precipitation events delivering at least .01 inches of water, and initial leaf density (for individual oak and maple leaf samples) have been tested as potentially useful covariates for explanation of differences among treatment means detected by ANOVA.

As expected, we presently have a better understanding of factors affecting mass loss progress, for all three litter species, in the hardwood stands than in the plantations. ANACOV has explained all differences between hardwood stand subunits detected by ANOVA for individual leaf and bulk litter samples of all three species. ANACOV to date has also explained differences among plantation subunits in mass loss from individual fascicle/leaf samples of pine and oak as well as from bulk samples of oak.

ANACOV results to date indicate that decomposition of all sample types in the hardwood stand subunits proceeded at least as fast in 1985 as in either 1986 or 1987. The same is the case for bulk samples of all three species in the plantation subunits. We suspect that the apparently faster dry matter mass loss from some sample sets during 1985 may be partly due to the earlier disbursal date for samples in that experiment. We have endeavored to disburse samples to the field as early each year as possible. Future ANACOV will focus in part on trying to find some logical covariate(s) (e.g., total elapsed time in the field, initial nutrient content, etc.) to explain this relationship among study years.

Differences between the three litter species studied, in their patterns of both dry matter mass loss and nutrient flux for the five elements studied, suggest that pine, oak, and maple decompose 1) according to different strategies, and 2) under the control of substantially different microbial populations. Therefore, we expect that the chance of detecting a modest environmental perturbation is increased by continued study of all three litter species rather than just one or two of them.

Our experimental design is clearly powerful enough to identify very subtle differences in the rates and patterns of bulk and individual fascicle/leaf decomposition, especially in the hardwood stand subunits. Our efforts in 1988 are focusing on 1) collection of the first year's data on litter decomposition in the presence of operational ELF electromagnetic fields, 2) broader use of covariate analysis to explain additional differ-

ences detected by ANOVA among years, monthly sampling dates, and subunits, and 3) providing substantial interpretation of the nutrient data sets now in hand.

Rhizoplane Streptomycetes

As in 1986, the emphasis of this work element during 1987 was focused on the enumeration and characterization of streptomycetes associated with the predominant mycorrhizal morphology type observed on red pine seedlings planted in 1984 in the three plantations. Sample sizes were maintained at six per plantation on each of the six sampling dates. Pre-weighed washed mycorrhizal fine root subsamples were macerated, serially diluted, and spread-plated onto starch casein agar amended with antifungal antibiotics. After 14 days incubation, counts of streptomycete levels as well as numbers of morphotypes were made. Representatives of each morphotype were subcultured for further characterization, in particular for ability to degrade complex organic compounds. Streptomycete level and morphotype number data were transformed to $\log_{10}$ and subjected to analysis of variance (ANOVA) for detection of differences first within the 1987 sampling season data and then between all years, sampling dates, and plantations. Preliminary efforts were made to use analysis of covariance (ANACOV) to explain differences detected by ANOVA among years, sampling dates and plantations.

There was no significant difference in either streptomycete levels or morphotype numbers among the control, antenna, and ground plantations during the 1987 field season. There was, however, a significant seasonal effect on both levels and morphotype numbers at each of the three plantations. Streptomycete levels from May through August were significantly higher than October levels at all three plantations; the September levels were higher than any month except for Jume. A more gradual decline in morphotype numbers occurred at all three plantations during the field season, with only the May and June numbers significantly higher than those in October. This general seasonal trend of significantly greater levels and numbers earlier in the sampling season than in later months was also observed during 1985 and 1986.

When comparing the 1985, 1986, and 1987 data sets for

streptomycete levels and morphotype numbers, significant differences were found among years and months but not between plantations. For levels, the 1987 values were significantly higher than for 1985 and 1986; the October values were significantly lower than for all other months. All three years were significantly different for morphotype numbers; the October values were also significantly lower than for all other months, although some other differences between other months were also found. Detectable differences for the log^{10}-transformed 3-year data set using ANOVA were about 1% for streptomycete levels and 5% for morphotype numbers for years, months, and plantations. Preliminary ANACOV conducted with several covariates did not completely explain the differences between years and months. However, only the 1986 and 1987 streptomycete levels and morphotype numbers remained significantly different. The October streptomycete levels were still significantly different from all others; fewer months had significantly different morphotype numbers. ANOVA and ANACOV with the 3-year streptomycete level data set minus the October values showed no significant differences between the remaining months (May - September). These results indicate that further ANACOV may explain the remaining differences detected by ANOVA among years.

In 1987, as in 1985 and 1986, the streptomycete morphotypes B and F were commonly isolated at all three plantations on all sampling dates. Seven additional morphotypes were also frequently detected at all three plantations during the 1987 field season; these types were also routinely detected during 1985 and 1986. Four morphotypes that were only infrequently detected in 1986 were not found in 1987; no new morphotypes were recovered. These results provide further evidence that similar, relatively stable streptomycete populations have become established on the red pine seedlings at all three ELF study plantations. Over half of the streptomycetes tested, representing all morphotypes detected during 1985, 1986, and 1987 were able to degrade calcium oxalate and cellulose; about 75% were able to degrade lignocellulose.

During 1988, this work element will focus on two objectives: 1) obtaining the first year's data on streptomycete levels and morphotype numbers associated with red pine mycorrhiza morphotype 3 in the presence of operational ELF electromagnetic fields, and 2) continuing development of covariate analysis to help explain differences in streptomycete levels and morphotype numbers between years, sapling dates, and plantations.

INTRODUCTION

Forest vegetation dominates the ELF Communications System antenna area. The litter decomposition subsystem of any forest ecosystem serves to 1) pool the nutrients relinquished by primary producers, 2) transform the essential nutrients remaining in litter or trapped by it into forms available for root uptake, and 3) release these nutrients in a regulated fashion for re-use by the autotrophs. The energy provided by litter decomposition also fuels heterotrophic dinitrogen fixation and the capture of nutrients washed from the atmosphere or leached from living plants. As heterotrophic microorganisms, streptomycetes have also been implicated in the calcium and phosphorus nutrition of conifer mycorrhizae, and could influence mycorrhizosphere microbial composition through production of antibiotics, growth factors, etc. Due to the large quantities of potentially available plant nutrients found in the litter component of forest biomass, knowledge of key decomposition processes and their rates is essential to conceptualization of ecosystem dynamics.

Organic matter decomposition is primarily accomplished by heterotrophic microorganisms whose activities are regulated by the environment. Environmental factors which disrupt decomposition processes detract from the orderly flow of nutrients to vegetation. As a new and anthropogenic environmental factor, ELF electromagnetic fields merit investigation for possible effects on the litter decomposition subsystem.

In 1982, Michigan Technological University initiated research at the Michigan antenna site which would determine whether ELF electromagnetic fields cause fundamental changes in forest productivity and health. This research program includes two separate yet highly integrated projects, the Herbaceous Plant Cover and Tree Studies ("Trees") project and the Litter Decomposition and Microflora project. Work elements examining 1) rates of litter decomposition and associated nutrient flux and 2) mycorrhizoplane streptomycete population dynamics were initiated simultaneously with those of the "Trees" project and on the same

study units. The two work elements comprising this project complement and extend the baseline studies of the "Trees" project. The information obtained will be used for comparison of pre-operational and operational status of the study variables to evaluate possible ELF electromagnetic field effects on the local forest ecosystem. After five years, and considerable refinement, we believe that the research studies representing the two work elements of this project are both biologically defensible and statistically rigorous. The overall objectives of these work elements are to determine the impacts of ELF electromagnetic fields on:

1) rates of litter decomposition and associated nutrient flux for three important local tree species (northern red oak, red maple, and red pine), and

2) populations of streptomycete species functionally associated with mycorrhizae of planted red pine seedlings.

Ultimately, the question of whether ELF electromagnetic fields impact these segments of forest communities will be answered by testing various hypotheses (Table 1) based on the results of relatively long-term studies.

Table 1. Critical null hypotheses which will be tested to fulfill objectives of the ELF environmental monitoring program Litter Decomposition and Microflora project.

I. There is no difference in the level of foliar litter decomposition (dry matter loss) achieved, or the seasonal pattern by which it proceeds, for each study species (northern red oak, red maple, or red pine), that cannot be explained using factors unaffected by ELF antenna operation.

II. There is no difference in the levels of foliar litter nutrient (N, P, K, Ca, Mg) flux achieved, or the seasonal patterns by which they proceed, for each study species (northern red oak, red maple, or red pine), that cannot be explained using factors unaffected by ELF antenna operation.

III. There is no difference in the level or the seasonal pattern of mycorrhizoplane streptomycete populations on the planted red pine seedlings that cannot be explained using factors unaffected by ELF antenna operation.

IV. There is no difference in the representation of different identifiable strains of mycorrhizosphere streptomycetes on the planted red pine seedlings that cannot be explained using factors unaffected by ELF antenna operation.

PROJECT DESIGN

Overview of Experimental Design

Emphasis has been placed from the beginning on development of a statistically rigorous experimental design capable of separating potentially subtle ELF field effects from the natural variability associated with soil, vegetational, climatic and temporal factors. Consequently, in order to most effectively test our hypotheses, we have fully integrated our studies into those of the "Trees" project, permitting us to take full advantage of both that project's basic field design and the extensive data collected by that project on the tree, stand and site factors which influence or regulate the processes and populations we are measuring (Table 2). The measurements made and the associated analyses are discussed more thoroughly in the following sections.

The experimental designs integrate direct measures with site variables, and are a common thread through the work elements of both projects due to shared components of the field design. Because of the similarity in analyses, an understanding of this experimental design is essential. However, the rationale and progress for measurements in each work element of this study are necessarily unique and will be discussed separately in the following sections.

Field Design

The electromagnetic fields associated with the ELF system will be different at the antenna and ground locations (Anonymous, 1977). As a consequence, forest vegetation at each site could be deferentially affected by both above and below ground fields. Therefore, the general approach of the study required plots to be located along a portion of the antenna, at a ground terminal, and at a control location some distance from the antenna.

Table 2. Measurements needed to test the critical hypotheses of the ELF environmental monitoring program Litter Decomposition and Microflora project, the objective each group of measurements relates to, and the work elements which address the necessary measurements and analyses.

Hypothesis Number	Related Objective	Measurements	Work Elements
I	1	**Monthly determinations of dry matter loss, from bulk and individual leaf litter samples of oak, maple, and pine**[a]; climatic variables, soil nutrients, litter nutrients	1,(1),(6)[1]
II	1	**Monthly determinations of nutrient (N, P, K, Ca, Mg) mass flux, for 1 year, from bulk foliar litter samples representing oak, maple, and pine**; climatic variables, soil nutrients, dry matter loss	1,(1),(6)
III	2	**Monthly counts of streptomycetes associated with mycorrhizae from planted red pine seedlings**; climatic variables, soil nutrients, mycorrhiza density, seedling growth and moisture stress	1,(2),(4)
IV	2	**Monthly determinations of numbers of streptomycete strains associated with Type 3 mycorrhizae from planted red pine seedlings**; climatic variables, soil nutrients, mycorrhiza density, seedling growth and moisture stress	1,(2),(4)

[1] Numbers in parentheses refer to work elements in the Herbaceous Plant Cover and Trees project.

[a] Bold print designates the response variable; other lists are covariates.

The most general experimental design for the "Trees" project is a split-plot in space and time. Each unit (control, antenna, and ground) is subjected to a certain level of ELF field exposure and is subdivided into two stand types (subunits). Pole-sized hardwood stands and red pine (Pinus resinosa Ait.) plantations comprise the treatments for this level of the design (Herbaceous Plant Cover and Tree Studies, Annual Report 1986, Figure 1, page 5). Both stand type subunits at each field unit are divided into three contiguous plots to control variation. The time factor is the number of years in which the experiment is conducted for pre-operational and operational comparisons, or the number of sampling periods in one season for year to year comparisons. It is necessary to account for time since successive measurements are made on the same whole units over a long period of time without rerandomization. A combined analysis involving a split-plot in space and time is made to determine both the average treatment response (site difference) over all years, and the consistency of such responses from year to year (Steel and Torrie 1980).

Each unit follows this design with one exception. There is no pole-sized hardwood stand subunit at the ground unit because the necessary buffer strips would have resulted in the hardwood subunit being too distant from the grounded antenna for meaningful exposure. Thus one treatment factor (hardwood stands) is eliminated at the ground unit. Depending on the variable of interest, the stand type treatment factor may or may not be pertinent. In those cases where measurements are made on only one stand type, the stand type treatment factor is irrelevant and falls out of the analysis. All other factors remain unchanged.

Statistical Design

Analysis of variance (ANOVA) and analysis of covariance (ANACOV) are used in our studies to determine effects of treatments (year, subunit, monthly sampling date, and Elf field exposure) on decomposition progress and streptomycete population levels. The statistical design employed in both study elements reported here is a factorial design with blocking and covariates. The factors included in the design vary somewhat by experiment, but include year, month, unit, and blocking. Recall that unit represents the three ELF treatments, control, ground, and antenna. Separate analyses are conducted for the hardwood stand and pine plantation subunits to satisfy the assumptions required by the analysis of covariance model. These experiments are not split-plot experiments across time, a design frequently used in the "Trees" project, because the experimental units are destructively sampled to obtain the required measurements.

Blocking is employed to control variability in all experiments, but the definition of blocks varies between experiments. The unit of blocking in the streptomycete experiments is the plantation subunit, with 6 replicates per block. The unit of blocking for the bulk leaf litter experiments is the plot (3 plots per subunit), with 2 replicates per block. For the individual leaf samples, the location of each group of leaf bags (24 groups per subunit) is a block, from which one replicate bag is removed each month. The blocking employed produces a balanced incomplete block design. This design is dictated by the spatial separation of the ELF treatments.

Our experimental design directly controls experimental error to increase precision. Indirect or statistical control can also reduce variability and remove potential sources of bias through the use of covariate analysis. This involves the use of variables (covariates) which are related to the variable of interest (variate). Covariate analysis removes the effects of an environmental source of variation that would either inflate the experimental error or inappropriately increase the variability

explained by the treatments. Identification of covariates which are both biologically meaningful and independent of treatment effects is one of the most important steps in our current analysis. Covariates will have to be shown to be unaffected (both directly and indirectly) by ELF fields before they can be legitimately used to explain (with respect to ELF fields) any differences in response variables between years or units. The independence of the ambient conditions covariates will be tested by the "Trees" project.

Covariates under examination differ among the dependent variables considered (Table 2). Most analyses use climatic variables computed from weather data, such as monthly mean air temperature, monthly mean soil temperature, monthly total precipitation and the number of precipitation events each month. Depending on the variable of interest, microsite factors will also be considered. Other factors considered are more specific to the observation; for example, other covariates in the analysis of mycorrhizoplane streptomycete populations could include seedling diameter, seedling height, current season seedling shoot length, simultaneous Type 3 mycorrhiza density, and plant moisture stress. Analyses will be conducted to determine which of these are both biologically meaningful and statistically significant without violating the necessary assumptions required for the analysis of covariance (Cochran, 1957).

The adjusted treatment means presented for each ANOVA and ANACOV model employ the arc sin square root transformation of raw data. The adjusted treatment means presented for each ANACOV model are further adjusted for the covariate(s) used, and represent the transformed data after the treatment means have been adjusted for the effect of the covariate(s). Throughout the ANACOV discussion, differences detected between means are <u>after</u> the effect of the covariate(s) has been considered. Thus, for example, when it is stated that decomposition failed to progress during a given month, the interpretation should be that the covariate(s) adequately explained any change that may have occurred during that month.

As noted above, the experimental design appropriately supports statistical data analysis by three-way ANOVA and ANACOV. Nevertheless, the sample means presented in figures throughout this report are accompanied by bars indicating the bounds of 95 percent confidence intervals. These confidence intervals are provided as a means of depicting relative sample variability, and do not represent the multiple (or pairwise) comparisons associated with ANOVA or ANACOV, respectively. The error bars in the figures are based on small samples, the number of observations for each specific treatment combination. ANOVA and ANACOV are based on much larger samples, and tend to explain much more variability - partly because n is larger, but also because factors used for statistical blocking (e.g., location), which contribute to error in the confidence intervals, are included in the ANOVA model. The error bars on the figures are therefore quite conservative when compared to ANOVA results. In other words, a significant difference may be found by ANOVA or ANACOV even if all confidence intervals overlap, if a consistent and sufficient trend exists between at least two levels of a given factor (i.e., monthly sampling dates, years, or different hardwood stand or plantation subunits).

An example of systematic trends which ANOVA can detect, but which comparing confidence intervals cannot possibly find, can be developed from Table 30 (page 82) and Figure 33b (page 84). The ANOVA indicates highly significant differences ($p = .0001$), while the associated figure does not contain any intramonthly comparisons that appear significant. However, it should be noted that, for each month, samples from the antenna unit had more mass remaining than did those from the control unit. This relationship is extremely unlikely ($p = 0.5^{8} * 2 = .0078$) using a two-tailed binomial test. It is this type of systematic trend that the ANOVA model detects, thus increasing statistical power.

As sample size increases and/or sample variance decreases, detection of a statistically significant difference between treatments becomes increasingly likely. Yet the biological effect of the given treatments on the dependent variable remains

unchanged, and is either consequential (biologically significant) or not, regardless of the statistical significance achieved. According to Mize and Schultz (1985),

"Means can be consequentially and (or) statistically different. A consequential difference is a difference that is large enough to be important. A statistical difference is a difference that is larger than expected, given the variability of the characteristic that was studied. Sometimes, consequential differences are not statistically different. Also, statistical differences are sometimes not consequential. The researcher should be primarily interested in discussing the statistical significance of consequential differences."

Our experimental design with respect to litter decomposition is powerful enough to detect some statistical differences which, because of their small size, appear to be inconsequential. We view this situation to be highly preferable to the reverse situation. Nevertheless, we expect that careful use of ANACOV will explain additional differences (e.g., between certain years) detected by ANOVA.

WORK ELEMENTS

The work elements of the Litter Decomposition and Microflora project acknowledge the two diverse study areas included within this project. Data from several work elements of the "Trees" project are used to test each hypothesis posed by this project (Table 2). The following sections present a synopsis of the rationale for study, measures, and analyses conducted in each work element of this project.

ELEMENT 1: LITTER DECOMPOSITION AND NUTRIENT FLUX

Introduction

Litter decomposition comprises a complex of processes involving a variety of organisms engaged in the degradation of a wide range of organic substrates. Loss of dry matter mass over time from freshly fallen foliar litter samples has traditionally been used as a measure of fully integrated litter decomposition (Kendrick 1959, Jensen 1974, Millar 1974, Witkamp and Ausmus 1976). Both the accuracy and precision of dry matter mass loss as a sensitive index of organic matter deterioration, however, decline with time beyond approximately one year, depending on the ecosystem. Nutrient flux, on the other hand, provides continuously meaningful ecological information. We are also finding that mass loss characterization on the basis of individual leaves provides additional biologically meaningful information about the decomposition process and the rates at which it naturally proceeds for different litter species, beyond that provided by study of mass loss for bulk samples. Bulk sample estimates of mass loss rates actually represent running averages of the decomposition rates operating in the individual leaves comprising the bulk sample. These average rates are nevertheless essential for conversion of nutrient concentrations determined for bulk litter samples from percent values to masses for calculation of nutrient flux. The increased sample sizes accompanying individual leaf studies also permit more accurate establishment of decomposition rates for comparison between subunits, years, and monthly sampling dates.

Microfloral population shifts have been shown to influence the rate of total litter decomposition (Mitchell and Millar 1978). Conversely, dry matter mass loss and nutrient flux are useful measures of the impact of environmental perturbations on the integrated activities of the litter biota. The methods employed in these studies integrate the activities of all but the largest soil fauna, and ELF fields represent one possible cause

of environmental perturbation.

Studies of litter decomposition and associated nutrient flux extend the usefulness of litter production data collected in the course of forest vegetation studies. Knowledge of litter biomass production and nutrient content conversely provide one link between the overstory and forest floor components of the forest ecosystem.

The forest vegetation at all three study sites is classified in the *Acer*-*Quercus*-*Vaccinium* habitat type (Coffman *et al.* 1983). The two hardwood species selected for study, northern red oak (*Quercus rubra*) and red maple (*Acer rubrum*), are common to both of the hardwood stand subunits. The conifer species selected for study (*Pinus resinosa*) exists as scattered mature specimens throughout the area. These three study species represent a range of decomposition strategies and rates. Red pine was also selected because the influence of fragmentation can be eliminated through experiments with individual fascicles.

Since the 1986 Annual Report was written, a third year's experience with red pine, northern red oak, and red maple foliar litter decomposition and nutrient flux has been gained on the antenna, ground, and control units. The 1986-87 study represented the fourth year of experience with red pine on the antenna and ground units. Experience to date supports the contention that mass loss and nutrient flux over time from freshly fallen foliar litter can be characterized with sufficient precision to detect subtle environmental perturbations.

Methods

Litter decomposition is being quantified as percent change over time in dry matter and nutrient (N, P, K, Ca, and Mg) masses. Analysis of litter nutrient content is being conducted by the Soils Analysis Laboratory, School of Forestry and Wood Products, Michigan Technological University. Laboratory protocol includes analysis of NBS standard no. 1575 (pine needles), as every 20th sample for N and P, and as every 15th sample for

cations. Experiments are conducted annually and focus on the first year following each year's litterfall.

A single parent litter collection, from a single location, is made for each study species in order to avoid the effects of possible differences in substrate quality associated with geographically different litter sources. Also, differences in substrate quality among parent litter collections made in different years or at different collection sites, which might develop as a result of making separate parent litter collections at each of the ELF study sites due to different levels of exposure to ELF (76 Hz) electromagnetic (EM) fields at those study/collection sites, are avoided. Accommodation of the potential for either type of effect would complicate the experimental design and greatly increase the number of samples required in order to maintain the power of statistical tests. We feel that the additional expense attached to expanding the experimental design to include separate litter collections from each ELF study site is not warranted at this time. Should changes in northern red oak foliar nutrient concentrations be identified and attributed to ELF EM fields (Herbaceous Plant Cover and Tree Studies, Annual Report 1986, Element 7. Litter Production, pages 166-173), we will reconsider our experimental design to evaluate the effect of site specific differences in foliar litter quality on litter decomposition.

Ratios of fresh to dry matter mass and initial nutrient content are determined for 15 random samples taken at regular intervals during field sample preparation from each of the pine, oak, and maple litter parent collections. All mass loss data (dry matter as well as nutrient masses) are based on 30°C dry masses. Pre-weighed field samples are enclosed in nylon mesh envelopes (3 mm openings), disbursed in the field during early December, and retrieved monthly from early May to early December. All envelopes are constructed to lay flat on the ground. Snow cover at the study sites dictates early May to be the earliest possible recovery date, because samples are frozen to the ground until snowmelt is complete. Likewise, snow cover dictates early

November as the latest possible recovery date from the plantation subunits, because samples are frozen to the ground by the early December sampling date. Early December collections are possible in the hardwood stand subunits, where sample envelopes are less severely weathered by early December, and are still relatively easy to separate from the surrounding litter.

Raw data are expressed as the proportion (X) of original dry matter or nutrient mass remaining over time. Dry matter mass loss is being studied by an individual fascicle/leaf method as well as via bulk litter samples, while nutrient flux is determined solely for the bulk litter samples. Individual fascicles/leaves offer the opportunity to study decomposition of basic foliage units. Each individual fascicle or leaf is completely intact at the time of disbursal. The influence of fragmentation on individual pine fascicle decomposition is especially easy to eliminate by discarding any fascicles broken during the course of an experiment.

Sufficient samples were recovered each month to permit both 1) analysis of differences in dry matter and nutrient mass losses between subunits, years, and monthly sampling dates by ANOVA and ANACOV, and 2) analysis of single exponential model rate constants (k) derived by fitting the year's dry matter mass loss data for each species on each subunit to an equation of the form $Y = e^{-kt}$ (Wieder and Lang 1982). In the past, we have derived single exponential models using the program BMDPAR, designed for derivative-free nonlinear regression. Rate constants were compared statistically by calculation of confidence intervals based on asymptotic standard deviations. We will bring our use of the single exponential model up to date in the 1988 annual report. This will facilitate direct comparison of our results with those of other researchers who have placed greater emphasis on this form of analysis. Compared with ANOVA and ANACOV, determination of rate constants may de-emphasize the effect of a single month's mass loss progress on comparisons among treatment levels (i.e., years and subunits). This would provide a more conservative analysis, possibly resulting in detection of fewer statistically

significant differences between years and subunits. We also plan to test the log transformation of the single exponential model ($\ln Y = -kt$) as a desirable alternative model form. Models of this form tend to homogenize variances and are more easily expanded to incorporate additional independent variables.

Dry matter mass loss data are transformed to the arc sin square root of X, where X is the proportion remaining of original mass, to homogenize variances prior to correlation analysis, ANOVA, and ANACOV (Steel and Torrie 1980). The arc sin square root transformation is recommended for use with data expressed as decimal proportions less than 1.00, especially when proportions within a data set vary widely. The effects of transforming mass flux data for the five nutrient elements studied will be evaluated. The log transformation is most likely to apply to the nitrogen, phosphorus, and calcium data sets, where X values exceeding 1.00 are not uncommon.

In all statistical analyses performed, acceptance or rejection of the null hypothesis is based on $\alpha = .05$, regardless of the statistical test employed. Differences which are significant with $P \leq .05$ are presented along with the attained significance level (P) of the test statistic. Multiple range comparisons among significant differences detected by ANOVA are being conducted via Tukey's Honestly Significant Difference (H.S.D., or w) procedure (Dowdy and Wearden 1983, Steel and Torrie 1980). Significant differences detected by ANACOV are being identified by the least square means pairwise comparison procedure (SAS 1985). All analyses presented here have been conducted on the mainframe computer at MTU, using PROC CORR or PROC GLM of the Statistical Analysis System (SAS 1985).

Sufficient decomposition and weather data are available for a substantial modeling effort. Several weather variables have been evaluated as covariates to date. Decomposition progress over total elapsed time since sample disbursal to the field was correlated with running totals of air temperature degree days (ATDDRT, 4.4°C basis, 30 cm above soil surface), soil temperature degree days (ST5DDRT, 4.4°C basis, 5 cm below the soil surface),

and the number of days with precipitation events delivering at least .01 inches of water (PR.01RT). Our use of analysis of covariance (ANACOV) to explain differences detected by ANOVA has been introduced under Project Design (pages 11 - 16). Additional weather variables, as well as soil and vegetative cover variables, litterfall characteristics, and initial nutrient content of the parent litter collections will be evaluated as covariates in 1988, for the purpose of further explaining differences detected by ANOVA among years, sampling dates, and plantation or hardwood stand subunits. As a guiding principle, only variables which can be shown to be unaffected by ELF electromagnetic fields to date will be considered as potentially useful covariates, since ANOVA and ANACOV are proposed as our principle tools for detection of any ELF-induced shift(s) of litter decomposition rates.

1986-87 Study

Fresh-fallen red pine litter was again collected on polyethylene tarps (provided with drainage) spread in the LaCroix red pine plantation near Houghton, due to 1) its proximity to MTU, and 2) its remoteness from interfering ELF (76 Hz) electromagnetic fields. Fresh-fallen red maple litter was again collected near the Covered Drive, seven miles from Houghton, for the same reasons. Northern red oak litter was again collected just beyond the northeast edge of the control plantation subunit plot 3.

Bulk pine sample envelopes measured 22 cm x 28 cm; each contained 10 g (air dry mass) of the parent collection. Bulk maple and oak sample envelopes measured 44 cm x 28 cm; each contained 15 g (air dry mass) of the parent collection. For the 1986-87 study, individual leaf envelopes measured 22 cm x 28 cm, and each contained one pine fascicle, one oak leaf, and one 7 cm diameter disk of Whatman No. 1 filter paper.

In the past, individual leaf envelopes contained multiple tethered leaves of a single species, and one envelope per month per species was recovered from each plantation or hardwood stand

subunit plot. Instead of collecting 3 individual leaf envelopes (one per species) from one location per plot each month as previously, during the 1987 field season we collected 1 envelope (representing pine, oak, <u>and</u> filter paper) from each of 8 locations per plot each month. Three advantages to this modified method were forseen:

1. The individual study leaves of each species are more clearly independent of one another.
2. Recovery of individual leaf envelopes from 24 locations per subunit each month (instead of 3) better represents site variability on each subunit.
3. Filter paper disks appeared attractive as a litter species due to their high degree of initial uniformity.

The validity of the first two points seems assured. We do not expect that this adjustment in experimental design for the study of individual leaf decomposition will prevent comparison of individual leaf data collected in different years by the two methods. Regardless, the ability to compare antenna and ground subunits with the control subunits will be enhanced by the improvement in experimental design.

Filter paper disks did not provide the desired improvement over individual maple leaves. The filter paper disks appeared to weather irregularly in the field, and provided much less precise data than did the individual pine fascicles or oak leaves.

It should be emphasized that the experimental design regarding bulk litter envelopes remains unaltered. Ten bulk litter envelopes of each species were placed together at two locations on each of the three plots comprising each subunit. One bulk envelope per species was retrieved each month from each of these 6 locations per subunit.

1987-88 Study

Fresh-fallen red pine, northern red oak, and red maple foliar litter were collected again in 1987 as described for the 1986-87 study. The same experimental design established for the 1984-85 through 1986-87 studies is being followed for bulk litter

samples in the 1987-88 study. The same experimental design for individual fascicle/leaf study established with the 1986-87 study is being continued with the 1987-88 study, with the single exception that only pine fascicles and oak leaves are included.

Description of Progress

1986-87 Study

Tables 3 through 5 present mean dry matter mass losses (raw, untransformed data) for all individual fascicle/leaf samples retrieved in 1987 (by sampling date and subunit), along with standard deviations and minimum detectable differences (based on 95 percent confidence intervals for sample means). Tables 3, 4, and 5 present the data from all five study subunits for individual pine fascicles, oak leaves and filter paper disks, respectively. Overall, the data show that the following shifts in individual fascicle/leaf sample means should be detectable ($\alpha = .05$).

A. Pine
   1. Plantation Subunits - 9% (3% or less for 20 of the 21 means estimated)
   2. Hardwood Stand Subunits - 5% (2% or less for 15 of the 16 means estimated)

B. Oak
   1. Plantation Subunits - 12% (9% or less for 19 of the 21 means estimated)
   2. Hardwood Stand Subunits - 6% (4% or less for 15 of the 16 means estimated)

C. Filter Paper Disks
   1. Plantation Subunits - 21% (14% or less for 19 of the 21 means estimated)
   2. Hardwood Stand Subunits - 18% (10% or less for 6 of the 16 means estimated)

We are satisfied with the levels of detection obtained for pine fascicles and oak leaves, but not with the performance of the filter paper disks.

Tables 6 through 8 present mean dry matter mass losses for all bulk samples retrieved in 1987 (by sampling date and subunit), along with standard deviations and minimum detectable differences. Tables 6, 7, and 8 present the data from all five study subunits for bulk pine, oak, and maple samples, respectively. The following shifts in bulk sample means should be detectable.

Table 3. *Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1987, for individual red pine fascicles disbursed in early December, 1986.*

Sampling Date	Antenna Unit: Plantation Mean[a]	S.D.[b]	%[c]	Hardwood Stand Mean	S.D.	%
29 April	0.92	0.02	1	0.93	0.02	1
27 may	0.92	0.02	1	0.93	0.02	1
25 June	0.87	0.03	2	0.88	0.03	1
23 July	0.82	0.03	2	0.82	0.03	2
27 August	0.77	0.03	2	0.78	0.03	2
24 September	0.74	0.04	2	0.75	0.03	2
28 October	0.68	0.14	9	0.75	0.03	2
25 November				0.73	0.03	2

Table 3. (cont)

Sampling Date	Control Unit: Plantation Mean	S.D	%	Hardwood Stand Mean	S.D	%
29 April	0.92	0.02	1	0.93	0.02	1
27 May	0.91	0.03	1	0.93	0.02	1
25 June	0.86	0.02	1	0.90	0.02	1
23 July	0.80	0.03	2	0.83	0.03	2
27 August	0.74	0.04	2	0.77	0.03	2
24 September	0.73	0.03	2	0.75	0.06	5
28 October	0.72	0.03	2	0.72	0.03	2
25 November				0.74	0.02	2

Table 3. (cont)

Sampling Date	Ground Unit: Plantation Mean	S.D.	%
29 April	0.93	0.01	1
27 May	0.92	0.02	1
25 June	0.87	0.04	2
23 July	0.81	0.04	2
27 August	0.78	0.04	3
24 September	0.73	0.03	2
28 October	0.72	0.04	2
25 November			

a/ Proportion ($X=M_t/M_0$), where M_0 and M_t represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation.

b/ standard deviation

c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 30, or less depending on fragmentation)

Table 4. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1987, for individual northern red oak leaves disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
29 April	0.92	0.02	1	0.94	0.02	1
27 May	0.82	0.07	3	0.93	0.02	1
25 June	0.75	0.08	4	0.87	0.04	2
23 July	0.62	0.12	8	0.82	0.05	2
27 August	0.59	0.10	7	0.76	0.06	4
24 September	0.52	0.15	12	0.71	0.07	4
28 October	0.50	0.13	9	0.72	0.06	4
25 November				0.69	0.07	4

Table 4. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
29 April	0.91	0.03	1	0.94	0.02	1
27 May	0.83	0.06	3	0.91	0.04	2
25 June	0.76	0.10	5	0.89	0.06	3
23 July	0.66	0.10	7	0.80	0.06	3
27 August	0.62	0.09	6	0.77	0.07	4
24 September	0.57	0.12	9	0.73	0.06	3
28 October	0.47	0.11	9	0.70	0.05	3
25 November				0.66	0.09	6

Table 4. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.93	0.03	1
27 May	0.87	0.06	3
25 June	0.74	0.10	6
23 July	0.68	0.11	7
27 August	0.57	0.16	12
24 September	0.57	0.10	8
28 October	0.55	0.11	8
25 November			

a/ Proportion ($X=M_t/M_0$), where M_0 and M_t represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,\,as}$ * S.E./Mean, and expressed as a percentage of the sample mean

Table 5. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1987, for filter paper disks disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
29 April	0.96	0.09	4	0.98	0.06	3
27 May	0.95	0.10	5	0.89	0.19	9
25 June	0.98	0.08	3	0.86	0.23	11
23 July	0.94	0.13	6	0.82	0.24	12
27 August	0.90	0.18	8	0.75	0.16	9
24 September	0.85	0.28	14	0.63	0.23	15
28 October	0.79	0.31	14	0.65	0.22	15

Table 5. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
29 April	0.95	0.08	4	0.99	0.05	2
27 May	0.92	0.18	8	0.97	0.10	4
25 June	0.86	0.23	11	0.96	0.14	6
23 July	0.81	0.24	12	0.92	0.21	10
27 August	0.73	0.34	21	0.80	0.23	12
24 September	0.83	0.24	12	0.73	0.24	14
28 October	0.69	0.32	20	0.67	0.29	18

Table 5. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.98	0.06	3
27 May	0.91	0.24	11
25 June	0.90	0.19	9
23 July	0.88	0.20	10
27 August	0.91	0.18	9
24 September	0.91	0.20	10
28 October	0.77	0.23	12

a/ Proportion ($X=M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,11}$ * S.E./Mean, and expressed as a percentage of the sample mean

Table 6. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1987, for bulk red pine foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
29 April	0.94	0.01	1	0.94	0.01	1
27 May	0.94	0.02	2	0.93	0.01	1
25 June	0.91	0.03	3	0.89	0.02	2
23 July	0.86	0.02	3	0.82	0.01	1
27 August	0.80	0.02	3	0.77	0.01	1
24 September	0.77	0.01	2	0.74	0.01	1
28 October	0.75	0.02	2	0.73	0.01	2
25 November				0.71	0.01	1

Table 6. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
29 April	0.92	0.02	2	0.94	0.01	1
27 May	0.91	0.01	1	0.92	0.01	2
25 June	0.88	0.02	3	0.88	0.01	1
23 July	0.84	0.00	1	0.83	0.01	1
27 August	0.77	0.01	1	0.77	0.02	2
24 September	0.74	0.01	2	0.74	0.02	3
28 October	0.74	0.01	2	0.73	0.02	2
25 November				0.72	0.02	2

Table 6. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.93	0.01	2
27 May	0.92	0.02	2
25 June	0.90	0.01	2
23 July	0.85	0.02	2
27 August	0.78	0.01	2
24 September	0.74	0.03	5
28 October	0.75	0.01	2
25 November			

a/ Proportion ($X=M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{0.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean

Table 7. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1987, for bulk northern red oak foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
29 April	0.94	0.03	3	0.96	0.01	1
27 May	0.86	0.08	9	0.97	0.03	3
25 June	0.88	0.06	7	0.92	0.02	2
23 July	0.81	0.09	11	0.87	0.02	2
27 August	0.76	0.02	3	0.80	0.02	3
24 September	0.74	0.04	6	0.75	0.03	4
28 October	0.71	0.02	4	0.75	0.02	3
25 November				0.71	0.02	3

Table 7. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
29 April	0.95	0.02	3	0.95	0.01	1
27 May	0.92	0.02	2	0.93	0.02	2
25 June	0.90	0.03	4	0.90	0.02	2
23 July	0.85	0.01	2	0.86	0.01	2
27 August	0.78	0.03	3	0.80	0.03	4
24 September	0.74	0.05	7	0.71	0.07	10
28 October	0.74	0.03	4	0.74	0.02	3
25 November				0.70	0.03	5

Table 7. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.92	0.09	10
27 May	0.94	0.01	1
25 June	0.87	0.10	12
23 July	0.80	0.12	16
27 August	0.79	0.02	3
24 September	0.76	0.04	6
28 October	0.74	0.02	4
25 November			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.
b/ standard deviation
c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,3}$ * S.E./Mean, and expressed as a percentage of the sample mean

Table 8. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1987, for bulk red maple foliar litter samples disbursed in early December, 1986.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
28 April	0.81	0.07	10	0.85	0.04	6
27 May	0.75	0.06	8	0.84	0.05	6
25 June	0.69	0.06	9	0.83	0.04	5
23 July	0.65	0.06	10	0.77	0.05	7
27 August	0.61	0.05	8	0.72	0.05	7
24 September	0.54	0.05	10	0.66	0.05	8
28 October	0.54	0.04	7	0.67	0.05	9
25 November				0.64	0.05	8

Table 8. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
29 Aptil	0.85	0.01	1	0.87	0.02	2
27 May	0.79	0.02	2	0.83	0.02	2
25 June	0.77	0.02	2	0.84	0.02	2
23 July	0.72	0.03	4	0.81	0.03	4
27 August	0.65	0.03	5	0.75	0.04	6
24 September	0.62	0.04	7	0.71	0.03	5
28 October	0.60	0.03	5	0.70	0.04	5
25 November				0.67	0.03	4

Table 8. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
29 April	0.84	0.06	7
27 May	0.78	0.07	9
25 June	0.74	0.05	7
23 July	0.70	0.07	10
27 August	0.62	0.06	10
24 September	0.61	0.05	9
28 October	0.58	0.07	13
25 November			

a/ Proportion ($X=M_1/M_0$), where M_0 and M_1 represent the 30°C dry matter masses of samples initially and at time 1, respectively. Dry matter mass at time 0 was estimated from fresh to dry mass (30°C) ratios determined for separate random subsamples taken at the time of litter sample preparation. These samples were also used to determine initial nutrient content.

b/ standard deviation

c/ detectable difference: estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean

A. Pine
   1. Plantation Subunits - 5% (3% or less for 20 of the 21 sample means estimated)
   2. Hardwood Stand Subunits - 3% (2% or less for 15 of the 16 sample means estimated)

B. Oak
   1. Plantation Subunits - 16% (10% or less for 18 of the 21 sample means estimated)
   2. Hardwood Stand Subunits - 10% (5% or less for 15 of the 16 sample means estimated)

C. Maple
   1. Plantation Subunits - 13% (10% or less for 20 of the 21 sample means estimated)
   2. Hardwood Stand Subunits - 9% (8% or less for 15 of the 16 sample means estimated)

We are satisfied with the levels of detection obtained for bulk samples of all three species.

The individual pine fascicle and oak leaf samples provided comparable minimum detectable difference estimates to those for bulk pine and oak samples. This was due to the greater sample size associated with individual pine fascicles and oak leaves, and in spite of larger variances for the individual fascicles/leaves. In the 1986 Annual Report, it was noted that minimum detectable difference estimates for individual maple leaves were higher than those for bulk maple samples, due to greater sample variances and the smaller sample size for individual maple leaves than for individual pine fascicles and oak leaves. It was hoped that the greater initial uniformity of filter paper disks would contribute to lower variability in dry matter mass loss, and that filter paper disks would thereby prove to be a superior third individual leaf litter species. In fact, however, variability in filter paper disk mass loss was relatively high, resulting in higher detectable differences than obtained for bulk maple samples in spite of much larger sample size. Detectable differences in the hardwood stand vs the plantation subunits were similar for the bulk and individual fascicle/leaf samples of all three species. There was only a slight tendency for the hardwood stand subunits to demonstrate lower minimum detectable differences than the plantation subunits. Minimum detectable differ-

ences generally increased with elapsed time in the field.

ANOVA Results - Individual Fascicle/Leaf Samples

Individual Pine Fascicles

Table 9 presents the 3-way ANOVA table for detection of significant differences in dry matter mass loss among years, monthly sampling dates, and plantations; Table 10 presents the corresponding ANOVA table for the hardwood stands. Tables 11 and 12 present 1) means and standard errors for the treatments (years, months, subunits), 2) detectable differences for each treatment based on 95 percent confidence intervals, and 3) significant differences detected by ANOVA and identified by Tukey's H.S.D. procedure. Table 11 corresponds to the plantation ANOVA, and Table 12 corresponds to the hardwood stand ANOVA. Monthly samples were collected near the beginning of the months indicated for multiple comparisons.

Individual pine fascicles placed in the control plantation decomposed faster than those placed in the ground or antenna plantations. No difference was detected between the control and antenna hardwood stands. Comparing years in the plantations, 1987 samples decomposed fastest and 1985 samples slowest; in the hardwood stands, 1985 samples decomposed fastest and 1986 samples slowest. Significant monthly progress occurred in the plantations, while progress in the hardwood stands occurred from June through October. Detectable differences were extremely low, well below 2 percent of the yearly, monthly and subunit mean values. This accounts for the significance of some of the differences between very close mean values.

Figures 1a and 1b present comparisons of monthly progress in dry matter mass loss during the 1986-87 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. Figures 2 and 3 present corresponding data for the 1985-86 and 1984-85

Table 9. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual pine needles in the three plantation subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	79	15.57		76.69	0.0001	0.81
Year	2		0.13	26.18	0.0001	
Month	6		14.73	955.42	0.0001	
Plantation	2		0.02	4.42	0.0122	
Location	69		0.27	1.50	0.0058	
Error	1415	3.64				
Corrected Total	1494	19.21				

Table 10. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual pine needles in the two hardwood stand subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	56	12.87		113.04	0.0001	0.84
Year	2		0.52	127.01	0.0001	
Month	7		11.84	831.51	0.0001	
Hardwood Stand	1		0.00	0.21	0.6504	
Location	46		0.20	2.19	0.0001	
Error	1171	2.38				
Corrected Total	1227	15.25				

Table 11. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 9.

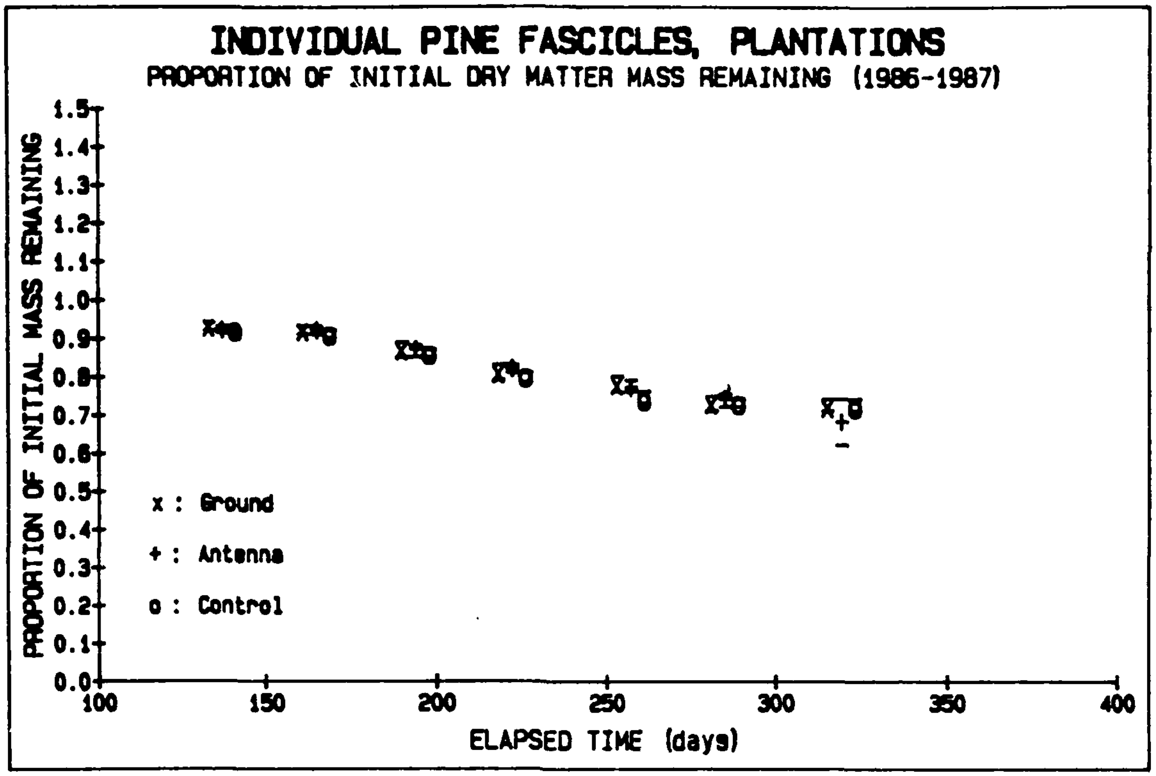
Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6				
1985	1.19	0.007	1.15	1985						
1986	1.17	0.007	1.17	1986	*					
1987	1.14	0.003	0.52	1987	*	*				
Month					1	2	3	4	5	6
May	1.31	0.005	0.75	May						
June	1.28	0.006	0.92	June	*					
July	1.22	0.005	0.80	July	*	*				
August	1.17	0.006	1.01	Aug	*	*	*			
September	1.11	0.005	0.88	Sept	*	*	*	*		
October	1.05	0.006	1.12	Oct	*	*	*	*	*	
November	1.03	0.006	1.14	Nov	*	*	*	*	*	*
Plantation					G	A				
Ground	1.17	0.006	1.01	Ground						
Antenna	1.17	0.005	0.84	Antenna						
Control	1.16	0.006	1.01	Control	*	*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 12. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 10.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6					
1985	1.11	0.007	1.24	1985							
1986	1.16	0.007	1.18	1986	*						
1987	1.15	0.003	0.51	1987	*	*					
Month					1	2	3	4	5	6	7
May	1.27	0.006	0.93	May							
June	1.26	0.006	0.93	June							
July	1.22	0.006	0.96	July	*	*					
August	1.18	0.006	1.00	Aug	*	*	*				
September	1.10	0.006	1.07	Sept	*	*	*	*			
October	1.05	0.006	1.12	Oct	*	*	*	*	*		
November	1.02	0.006	1.15	Nov	*	*	*	*	*	*	
December	1.03	0.006	1.14	Dec	*	*	*	*	*	*	
Hardwood Stand					A						
Antenna	1.14	0.005	0.86	Antenna							
Control	1.14	0.005	0.86	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.


INDIVIDUAL PINE FASCICLES, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1986-1987)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control

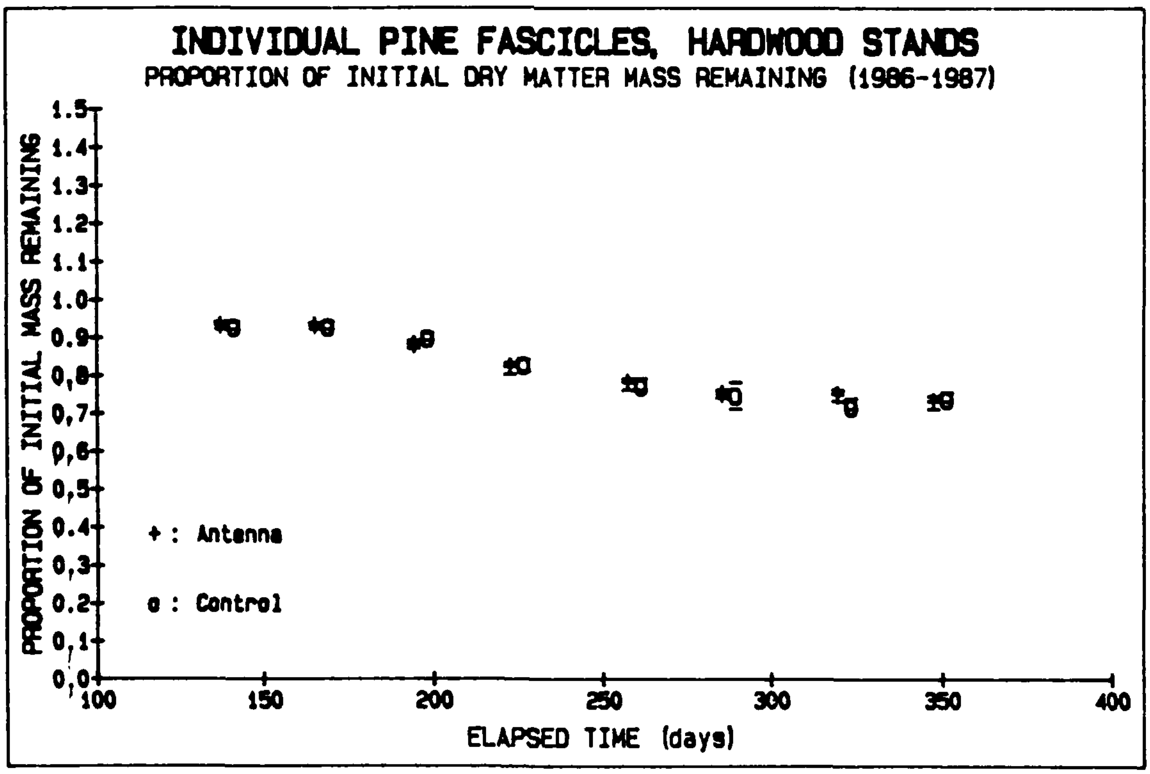
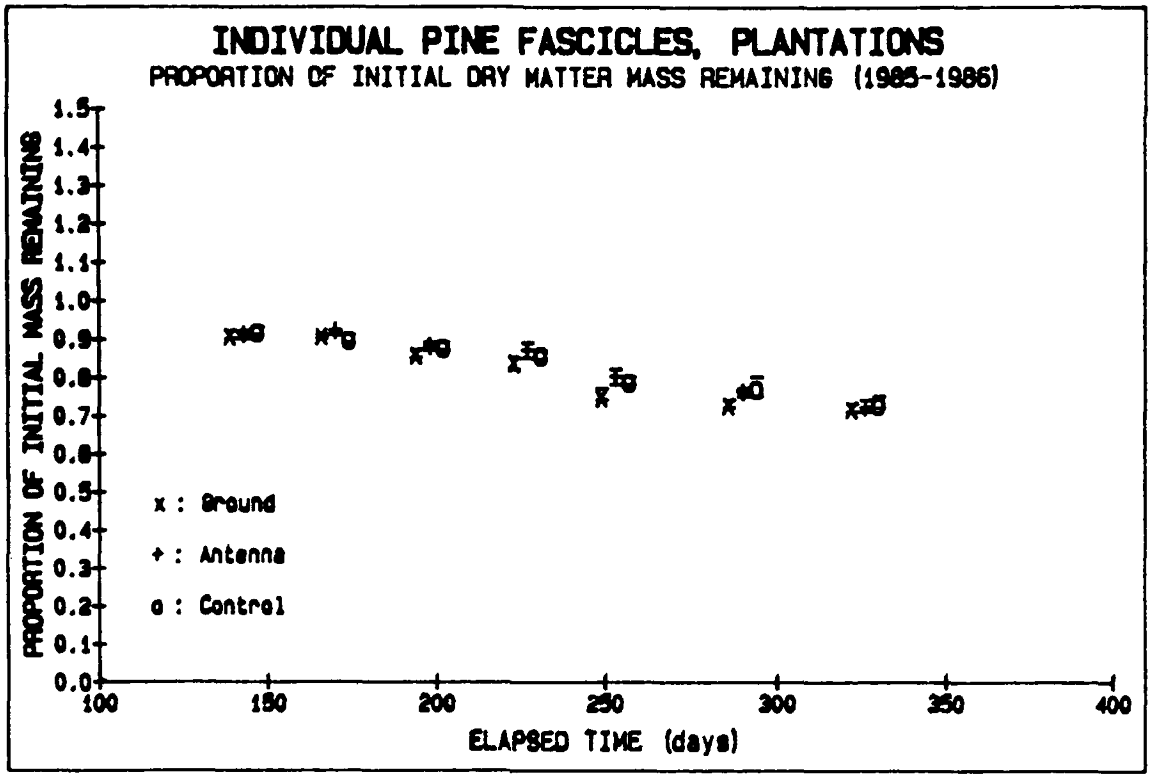

INDIVIDUAL PINE FASCICLES, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1986-1987)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
+ : Antenna
o : Control

FIGURE 1.


INDIVIDUAL PINE FASCICLES, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
x : Ground
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

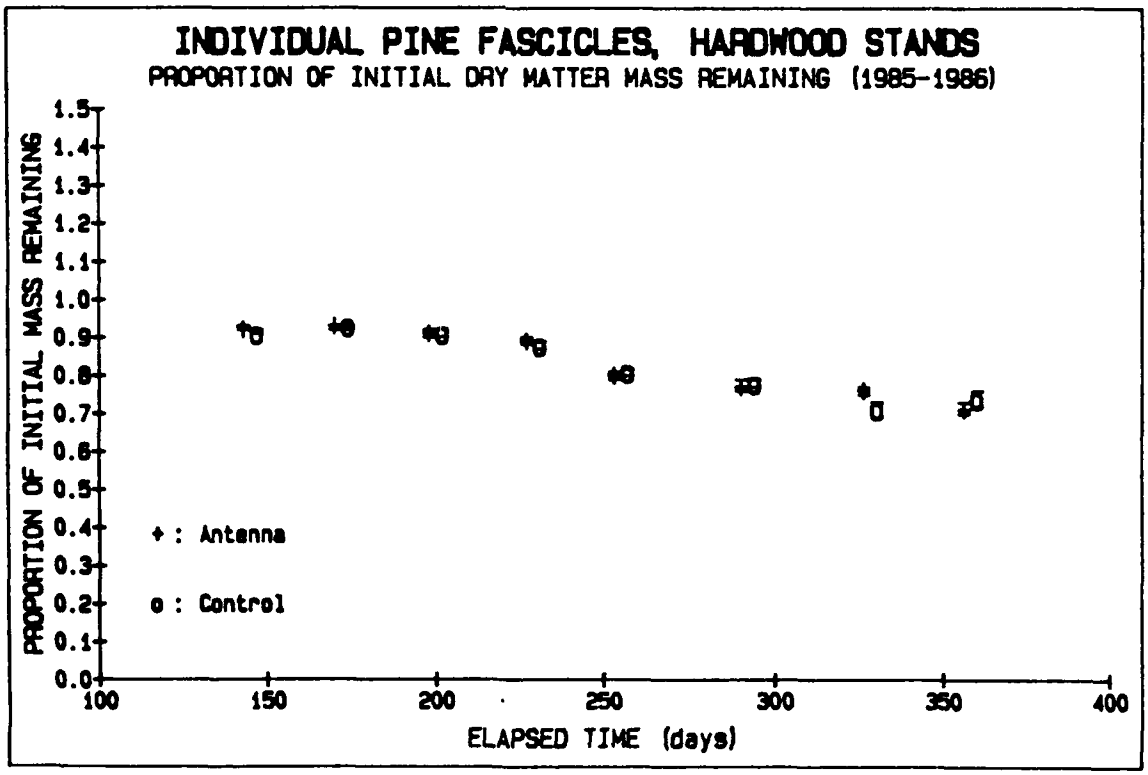
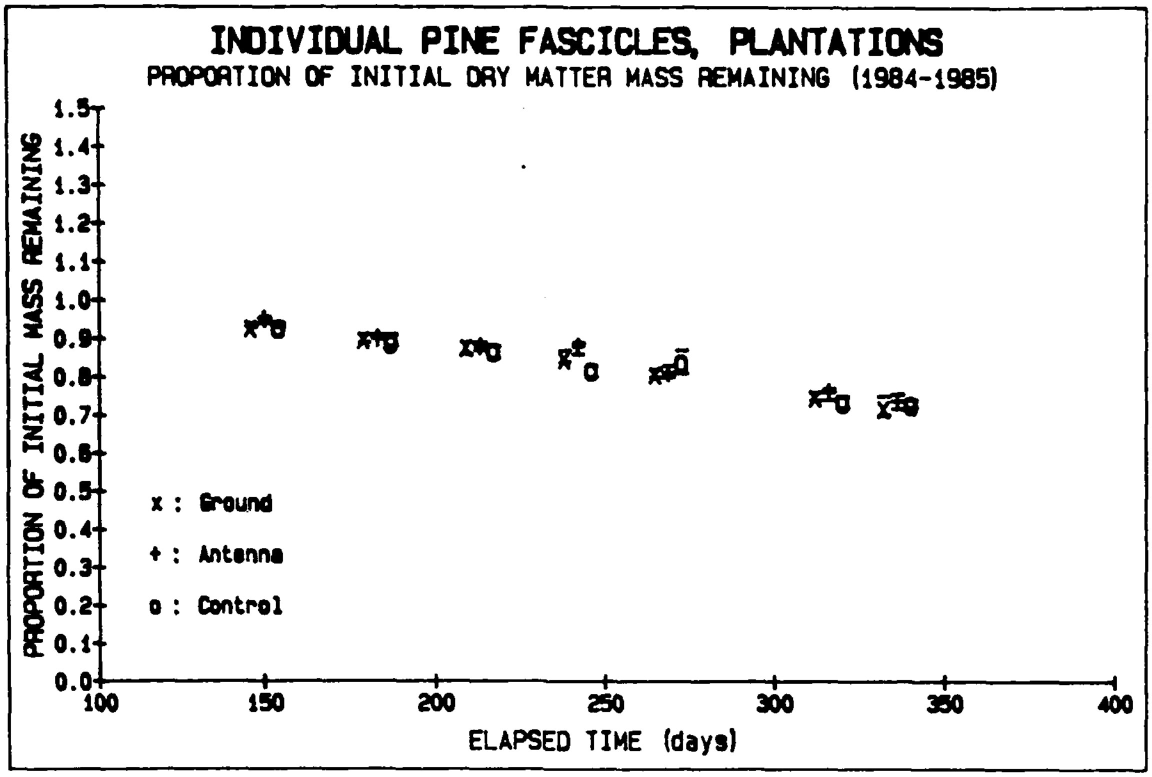

INDIVIDUAL PINE FASCICLES, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 2.


INDIVIDUAL PINE FASCICLES, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control

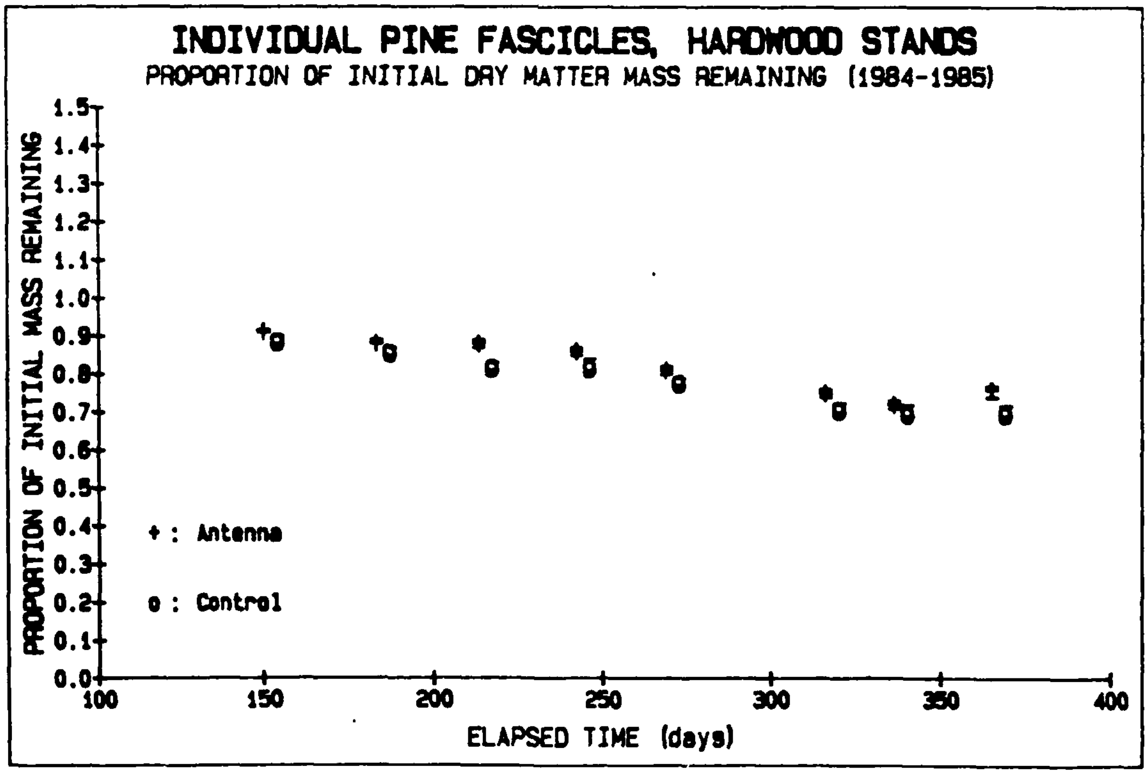

INDIVIDUAL PINE FASCICLES, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
+ : Antenna
o : Control

FIGURE 3.

FIGURE 4. INDIVIDUAL PINE FASCICLES, GROUND PLANTATION
PROPORTION OF INITIAL DRY MATTER MASS REMAINING

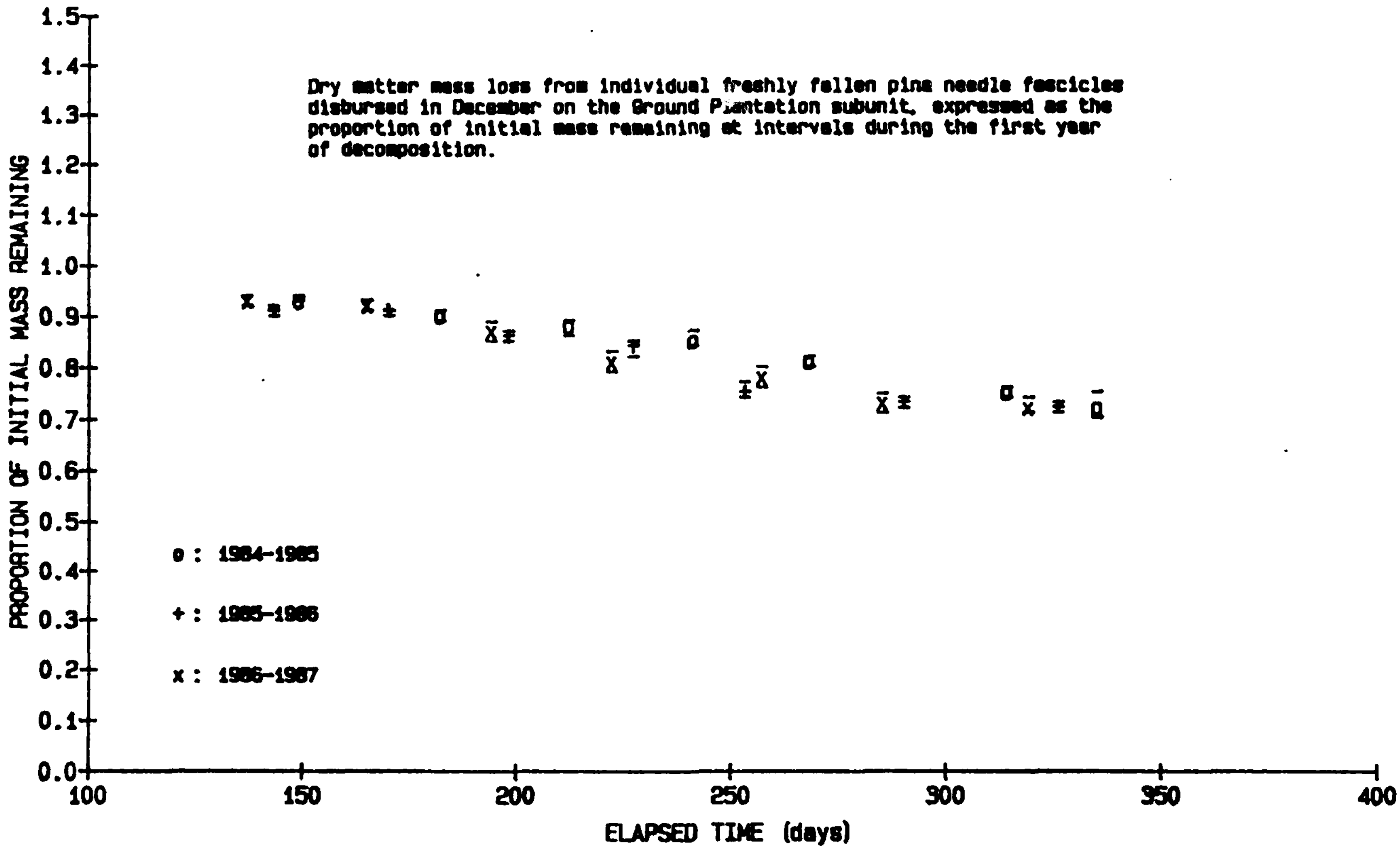


FIGURE 5.

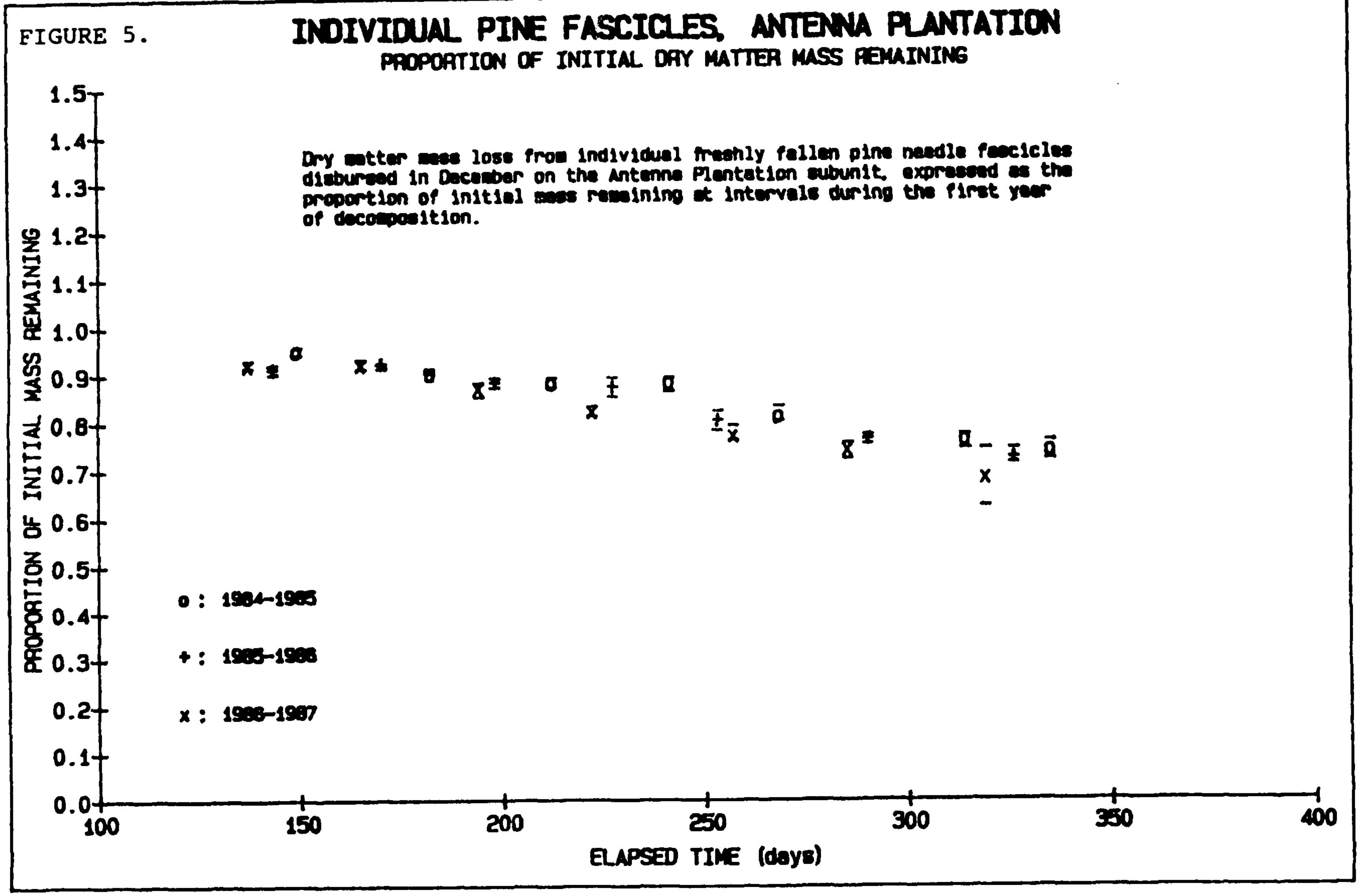

INDIVIDUAL PINE FASCICLES, ANTENNA PLANTATION
PROPORTION OF INITIAL DRY MATTER MASS REMAINING
Dry matter mass loss from individual freshly fallen pine needle fascicles disbursed in December on the Antenna Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
o : 1984-1985
+ : 1985-1986
x : 1986-1987
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 6.

INDIVIDUAL PINE FASCICLES, CONTROL PLANTATION

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

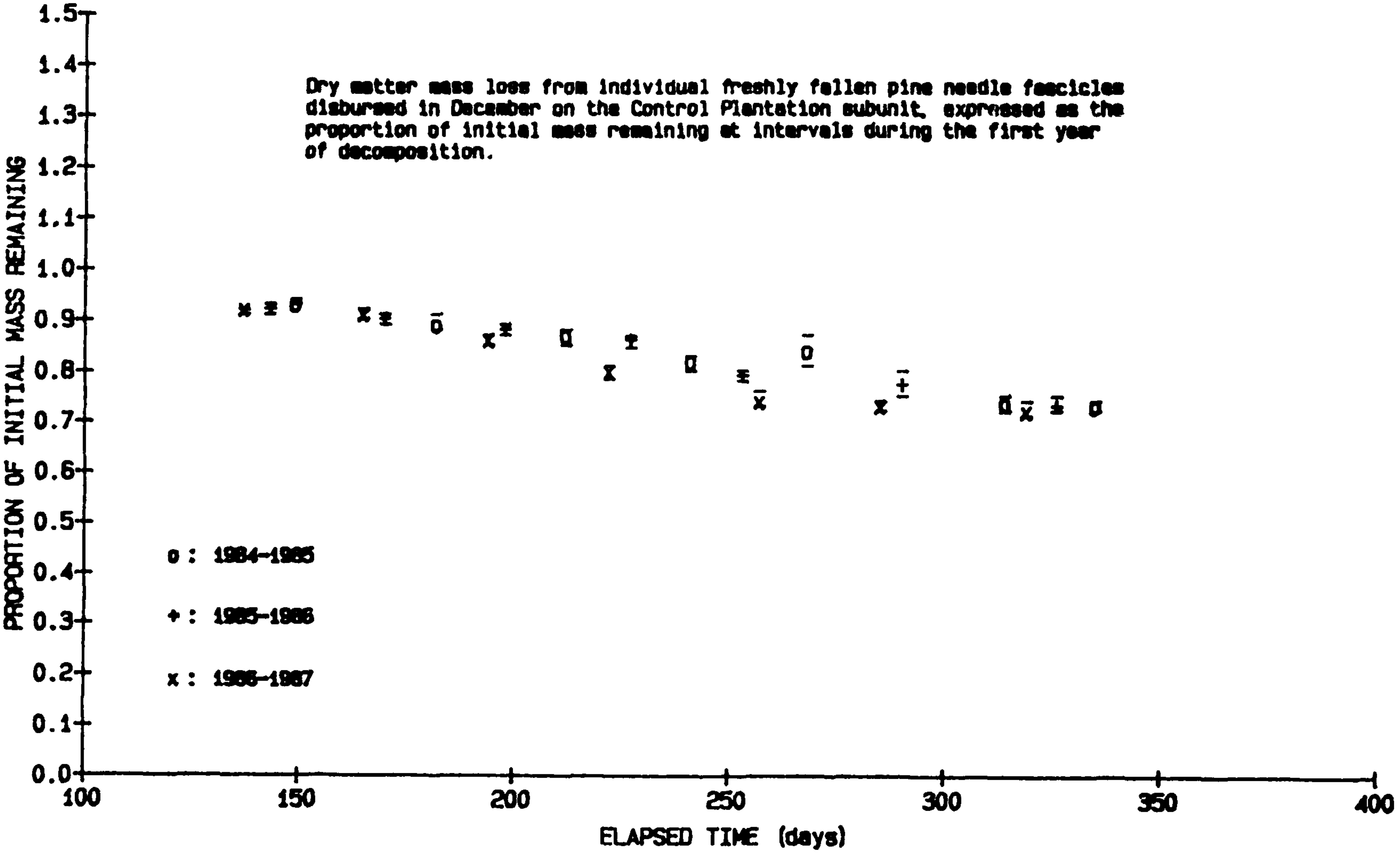


FIGURE 7.

INDIVIDUAL PINE FASCICLES, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

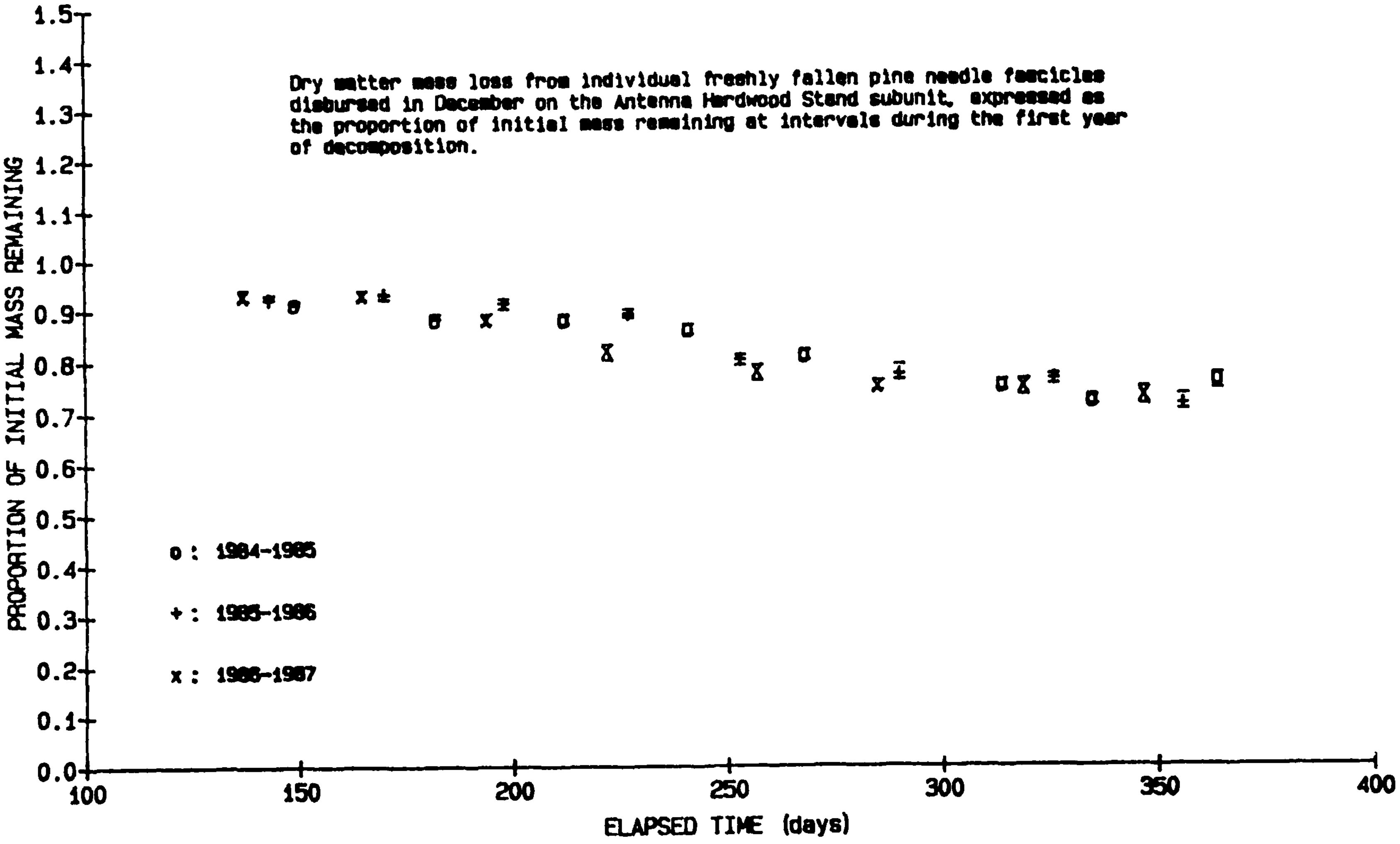
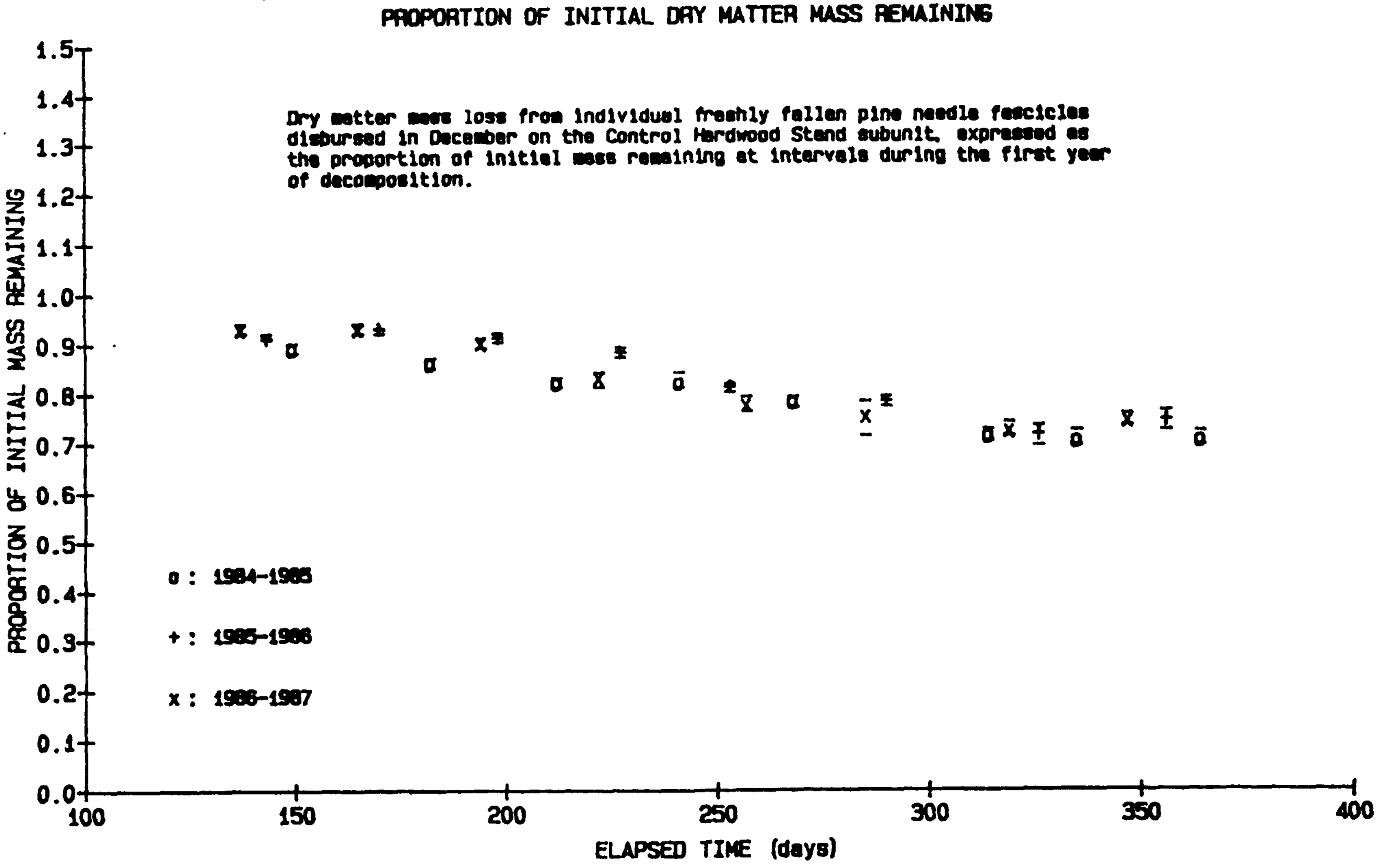


FIGURE 8. INDIVIDUAL PINE FASCICLES, CONTROL HARDWOOD STAND



studies, respectively. The general similarity among plantation and hardwood stand subunits is encouraging, and suggests that ANACOV might explain the differences detected by ANOVA. Some of the differences detected between subunits by ANOVA would be difficult to anticipate from these figures.

Figure 4 presents comparisons of monthly progress in dry matter mass loss during the 1984-85, 1985-86, and 1986-87 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 5 through 8 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands, respectively. While the significant differences detected by ANOVA are apparent, the differences between annual studies are not particularly striking, and suggest that ANACOV may explain them.

Individual Oak Leaves

Tables 13 and 14 present the ANOVA tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 15 and 16 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANOVAs, respectively.

Individual oak leaves placed in the antenna plantation decomposed faster than those placed in the control plantation. No differences were detected in decomposition rate between the two hardwood stands. Comparing years in the plantations, 1987 samples decomposed fastest and 1986 samples slowest; in the hardwood stands, 1985 and 1987 samples decomposed faster than 1986 samples. Significant monthly progress occurred in the plantations, while no significant progress was made in the hardwood stands during June or November. Detectable differences were very low, below 2.5 percent for yearly, monthly, and subunit mean values.

Figures 9a and 9b present comparisons of monthly progress

Table 13. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual oak leaves in the three plantation subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	79	42.17		45.07	0.0001	0.68
Year	2		1.92	81.03	0.0001	
Month	6		32.63	459.20	0.0001	
Plantation	2		0.08	3.23	0.0399	
Location	69		1.21	1.48	0.0076	
Error	1658	19.63				
Corrected Total	1737	61.80				

Table 14. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual oak leaves in the two hardwood stand subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	56	23.07		68.30	0.0001	0.75
Year	2		0.68	56.42	0.0001	
Month	7		21.58	511.10	0.0001	
Hardwood Stand	1		0.01	1.86	0.1731	
Location	46		0.52	1.87	0.0005	
Error	1267	7.64				
Corrected Total	1323	30.71				

Table 15. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 13.

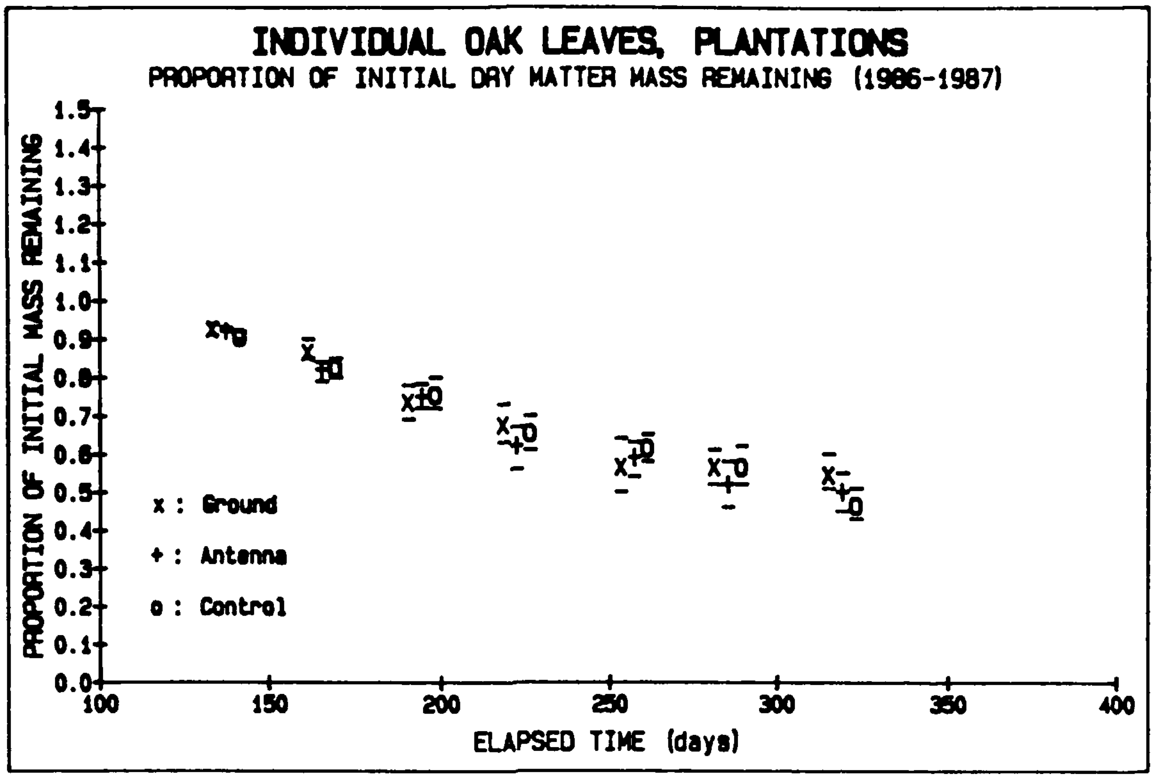
Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year								5	6	
1985	1.09	0.013	2.34	1985						
1986	1.15	0.013	2.22	1986				*		
1987	1.00	0.005	0.98	1987				*	*	
Month					1	2	3	4	5	6
May	1.29	0.011	1.67	May						
June	1.21	0.011	1.78	June	*					
July	1.14	0.011	1.89	July	*	*				
August	1.07	0.011	2.01	Aug	*	*	*			
September	0.99	0.011	2.18	Sept	*	*	*	*		
October	0.93	0.011	2.32	Oct	*	*	*	*	*	
November	0.89	0.011	2.42	Nov	*	*	*	*	*	*
Plantation							G		A	
Ground	1.09	0.011	1.98	Ground						
Antenna	1.06	0.011	2.03	Antenna						
Control	1.08	0.011	2.00	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 16. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 14.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year									5	6	
1985	1.10	0.011	1.96	1985							
1986	1.15	0.011	1.87	1986					*		
1987	1.13	0.004	0.69	1987						*	
Month					1	2	3	4	5	6	7
May	1.30	0.009	1.36	May							
June	1.26	0.009	1.40	June	*						
July	1.24	0.009	1.42	July	*						
August	1.17	0.009	1.51	Aug	*	*	*				
September	1.10	0.009	1.60	Sept	*	*	*	*			
October	1.02	0.009	1.73	Oct	*	*	*	*	*		
November	0.96	0.009	1.84	Nov	*	*	*	*	*	*	
December	0.96	0.009	1.84	Dec	*	*		*	*	*	
Hardwood Stand								A			
Antenna	1.13	0.008	1.39	Antenna							
Control	1.12	0.008	1.40	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.


INDIVIDUAL OAK LEAVES, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1986-1987)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
x : Ground
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

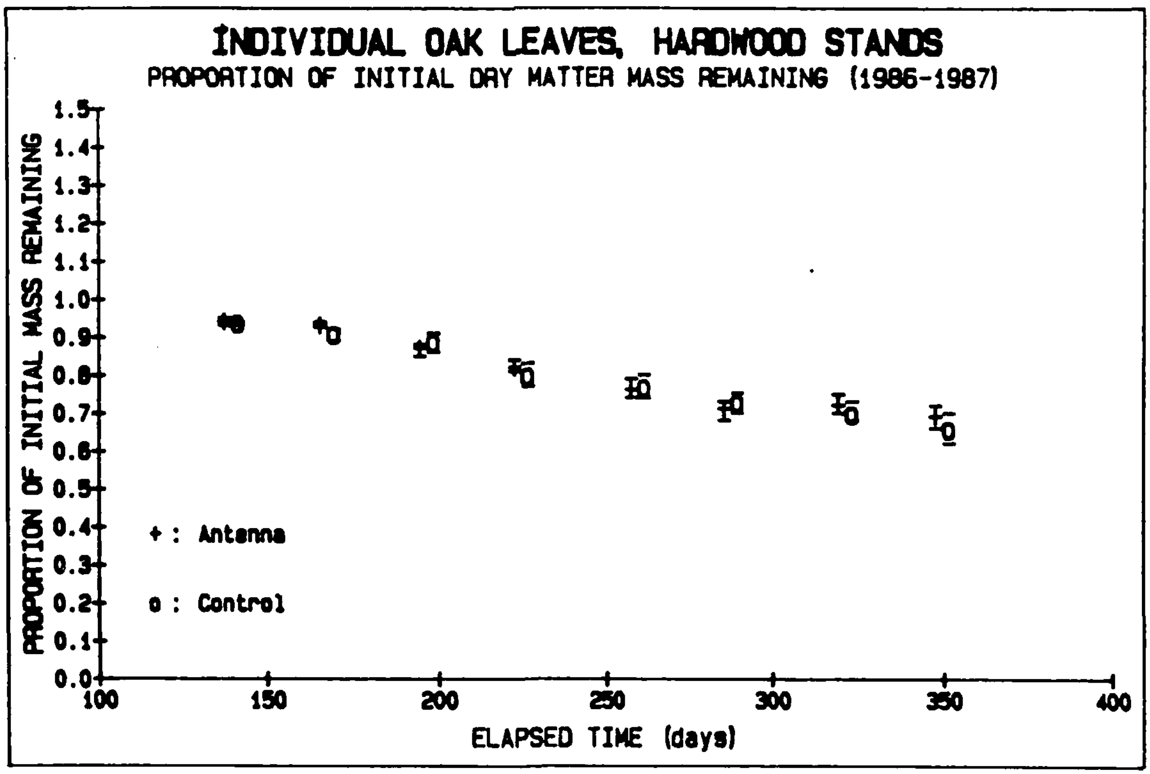
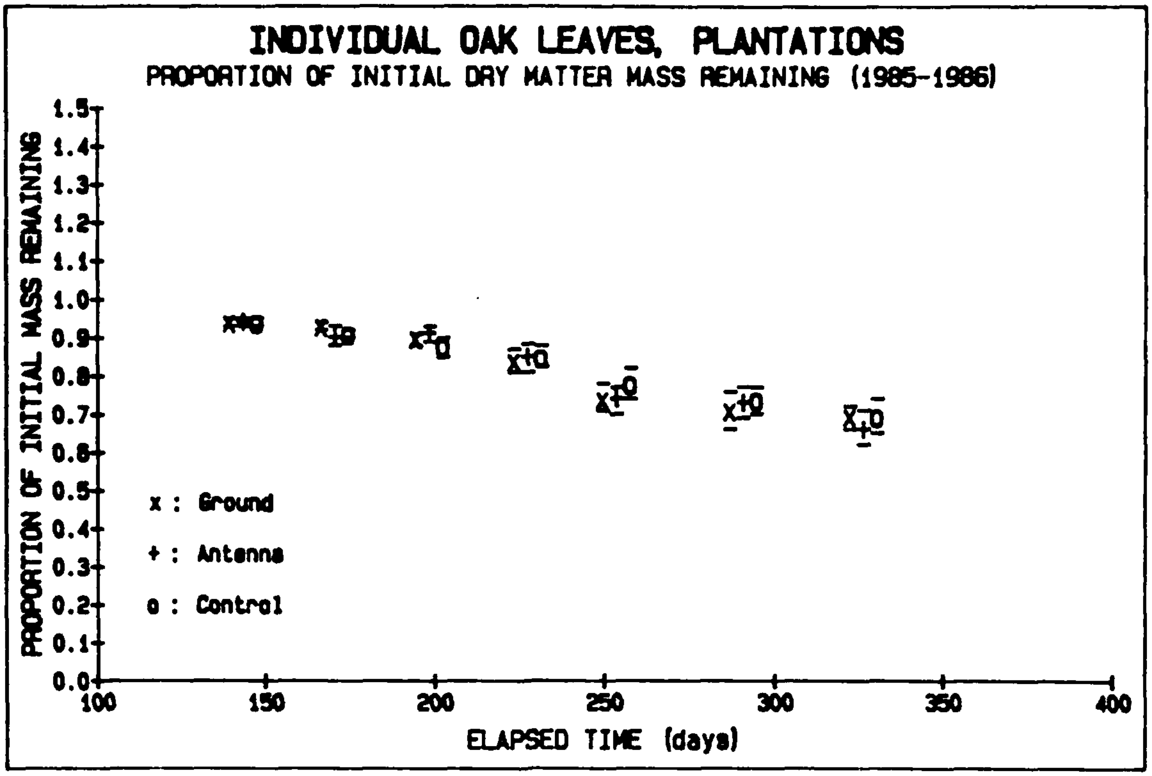

INDIVIDUAL OAK LEAVES, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1986-1987)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 9.


INDIVIDUAL OAK LEAVES, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control

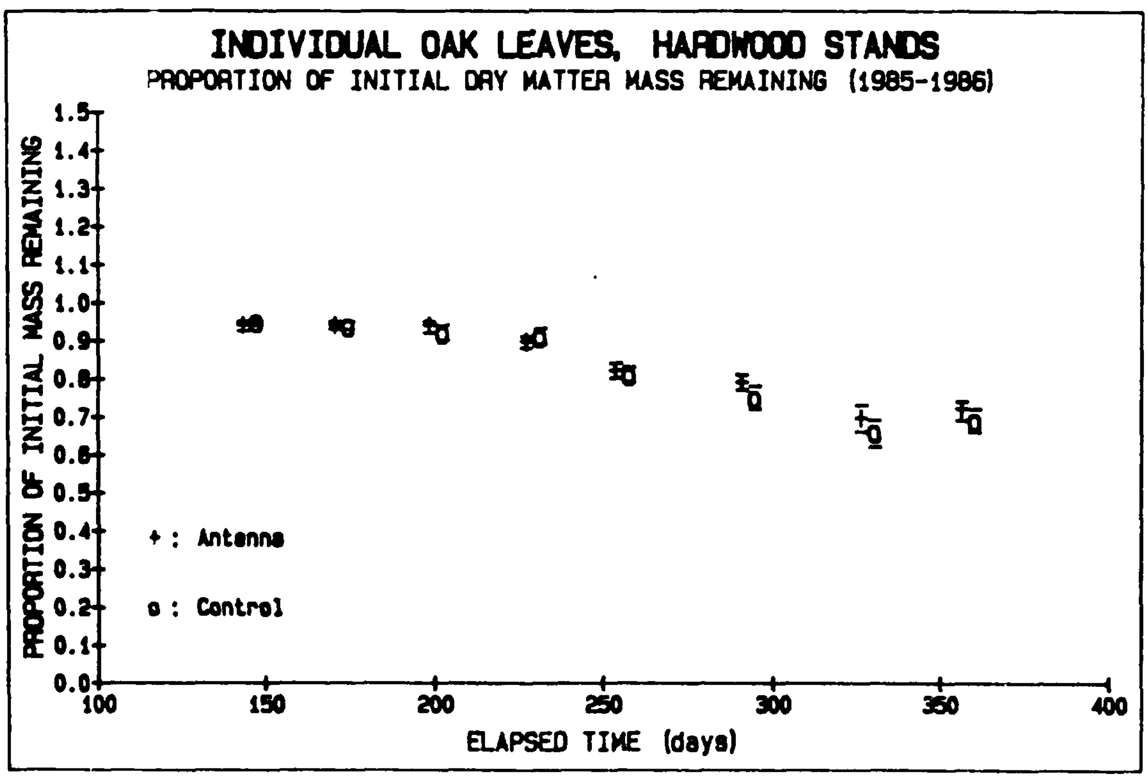
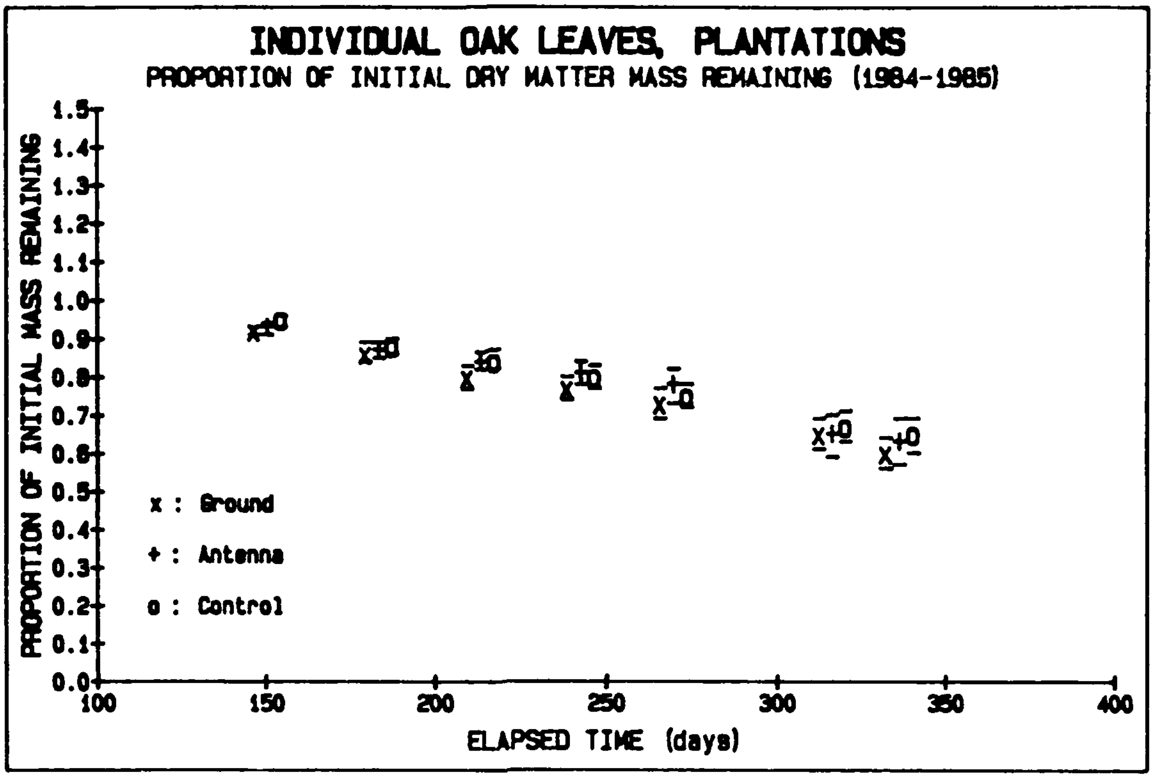

INDIVIDUAL OAK LEAVES, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
+ : Antenna
o : Control

FIGURE 10.


INDIVIDUAL OAK LEAVES, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control

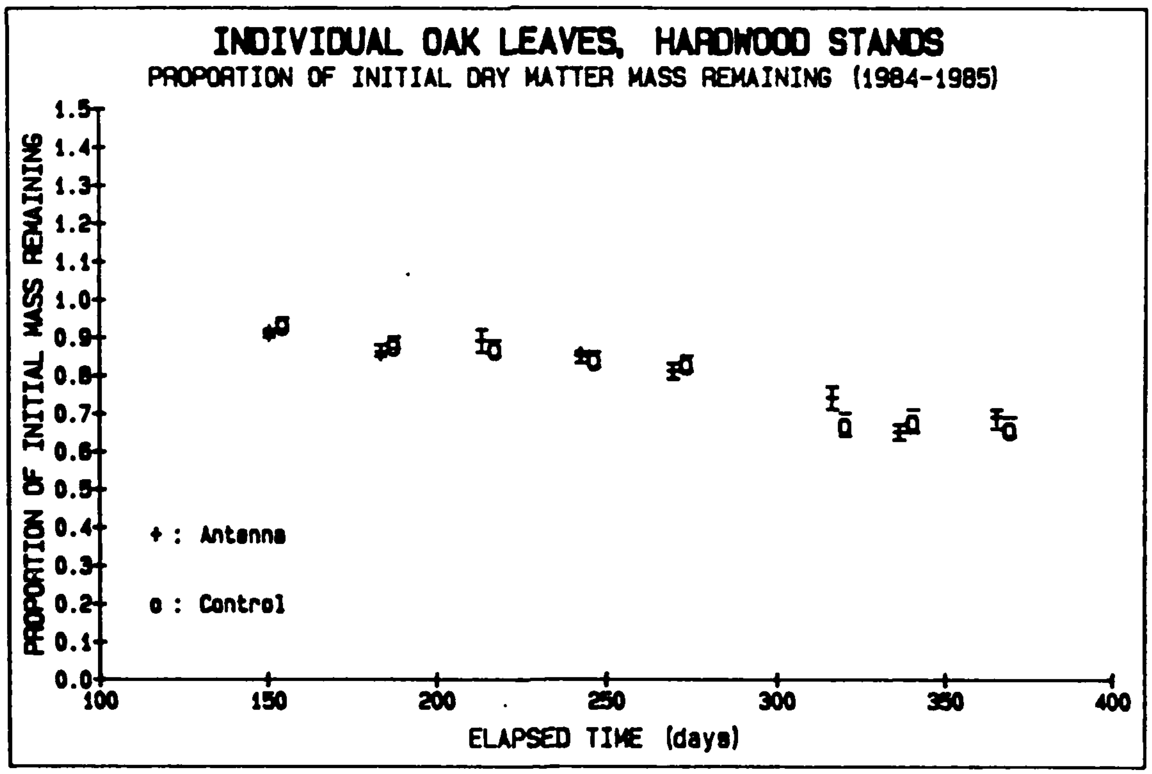

INDIVIDUAL OAK LEAVES, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
+ : Antenna
o : Control

FIGURE 11.

FIGURE 12.

INDIVIDUAL OAK LEAVES, GROUND PLANTATION
PROPORTION OF INITIAL DRY MATTER MASS REMAINING

Dry matter mass loss from individual freshly fallen oak leaves disbursed in December on the Ground Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

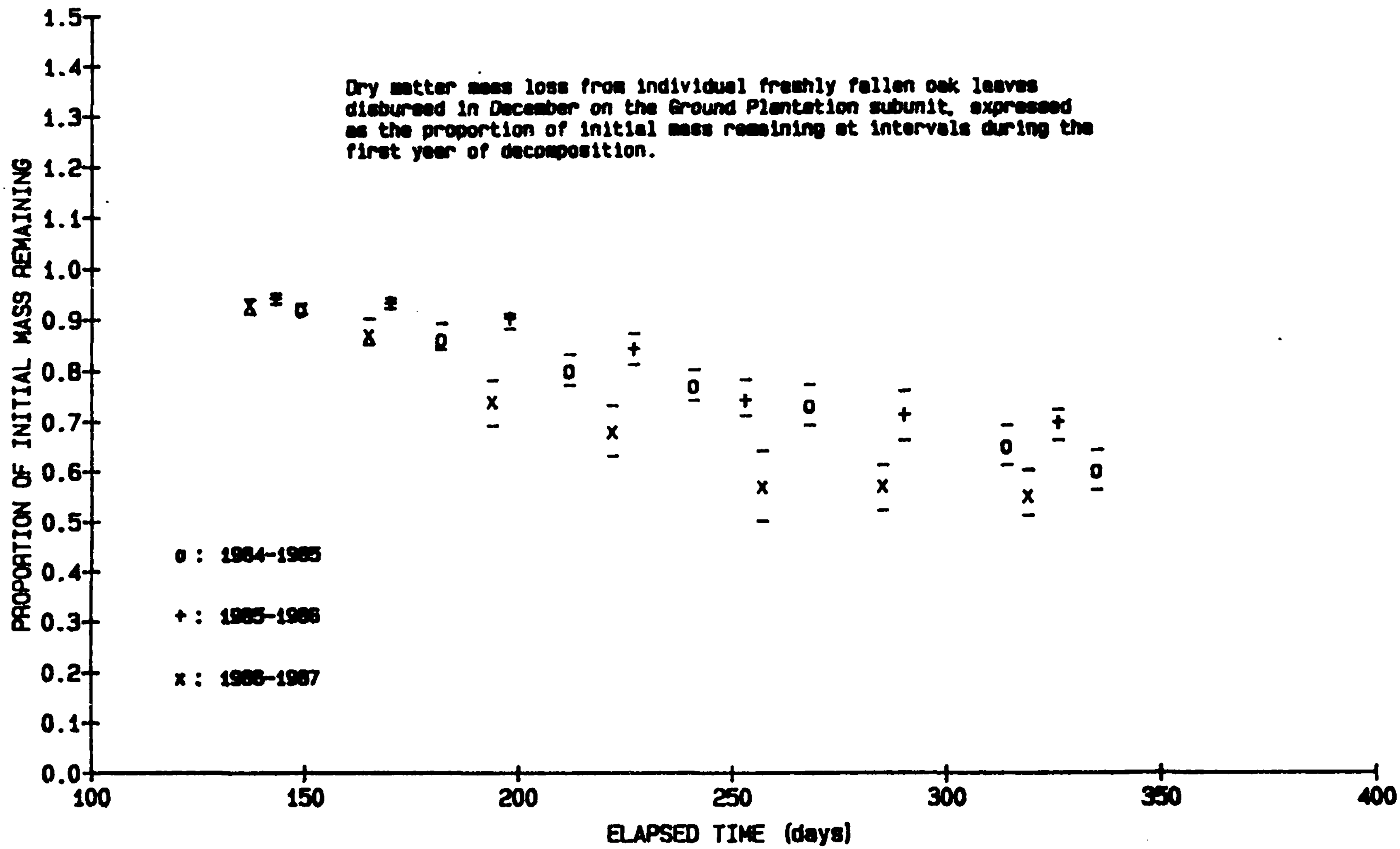


FIGURE 13.

INDIVIDUAL OAK LEAVES, ANTENNA PLANTATION

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

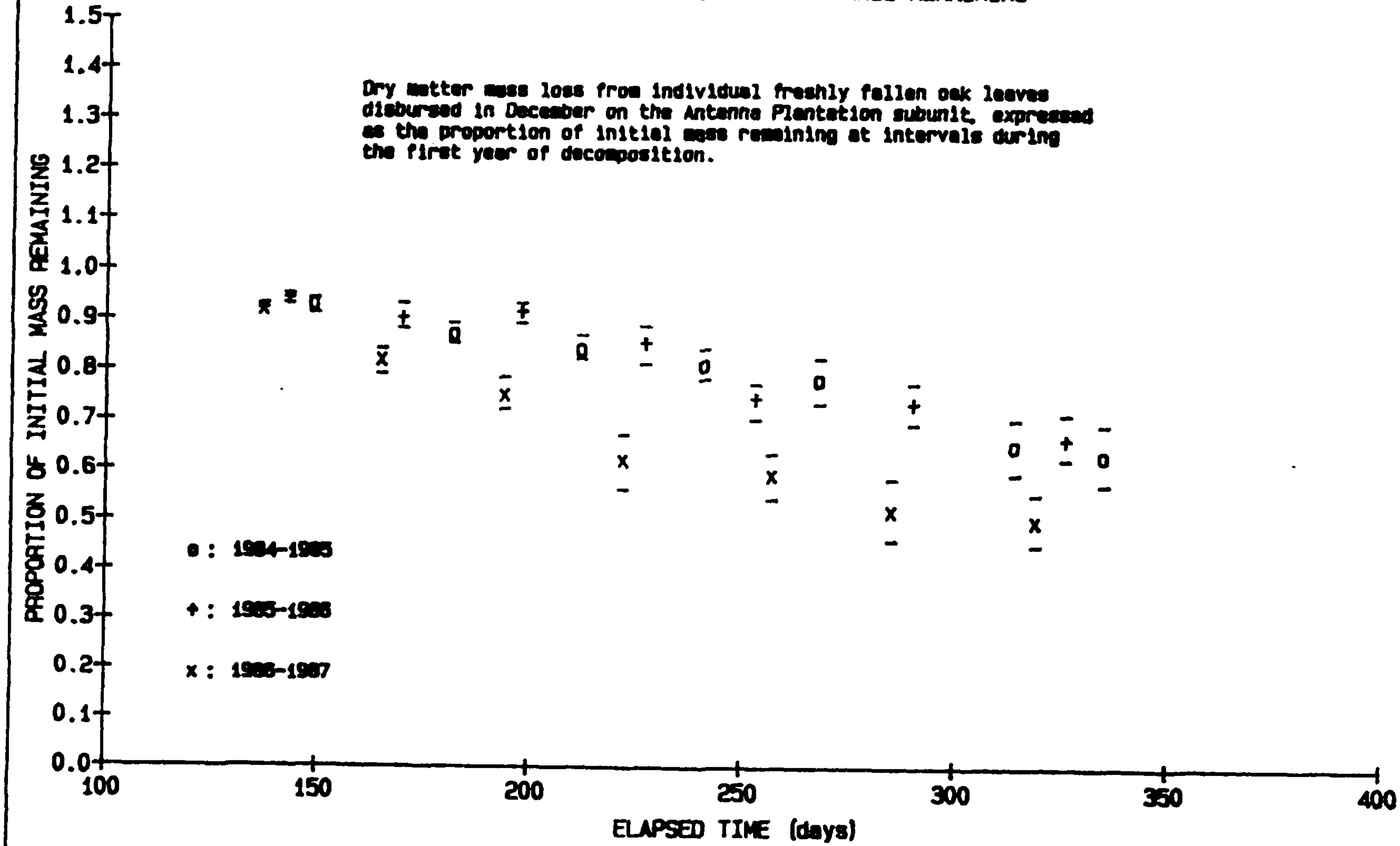
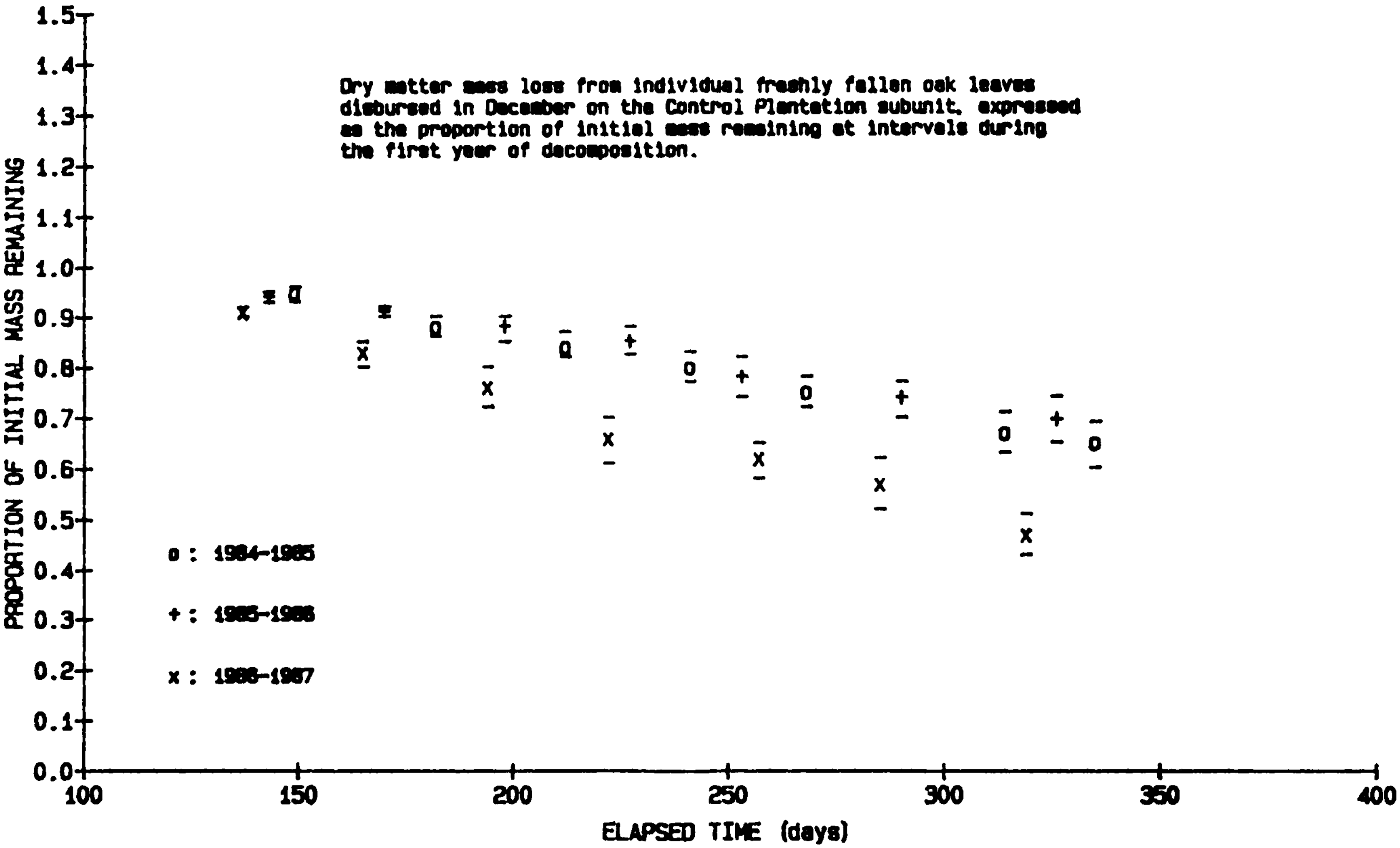


FIGURE 14.

INDIVIDUAL OAK LEAVES, CONTROL PLANTATION

PROPORTION OF INITIAL DRY MATTER MASS REMAINING



Dry matter mass loss from individual freshly fallen oak leaves disbursed in December on the Control Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

FIGURE 15.

INDIVIDUAL OAK LEAVES, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

Dry matter mass loss from individual freshly fallen oak leaves disbursed in December on the Antenna Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

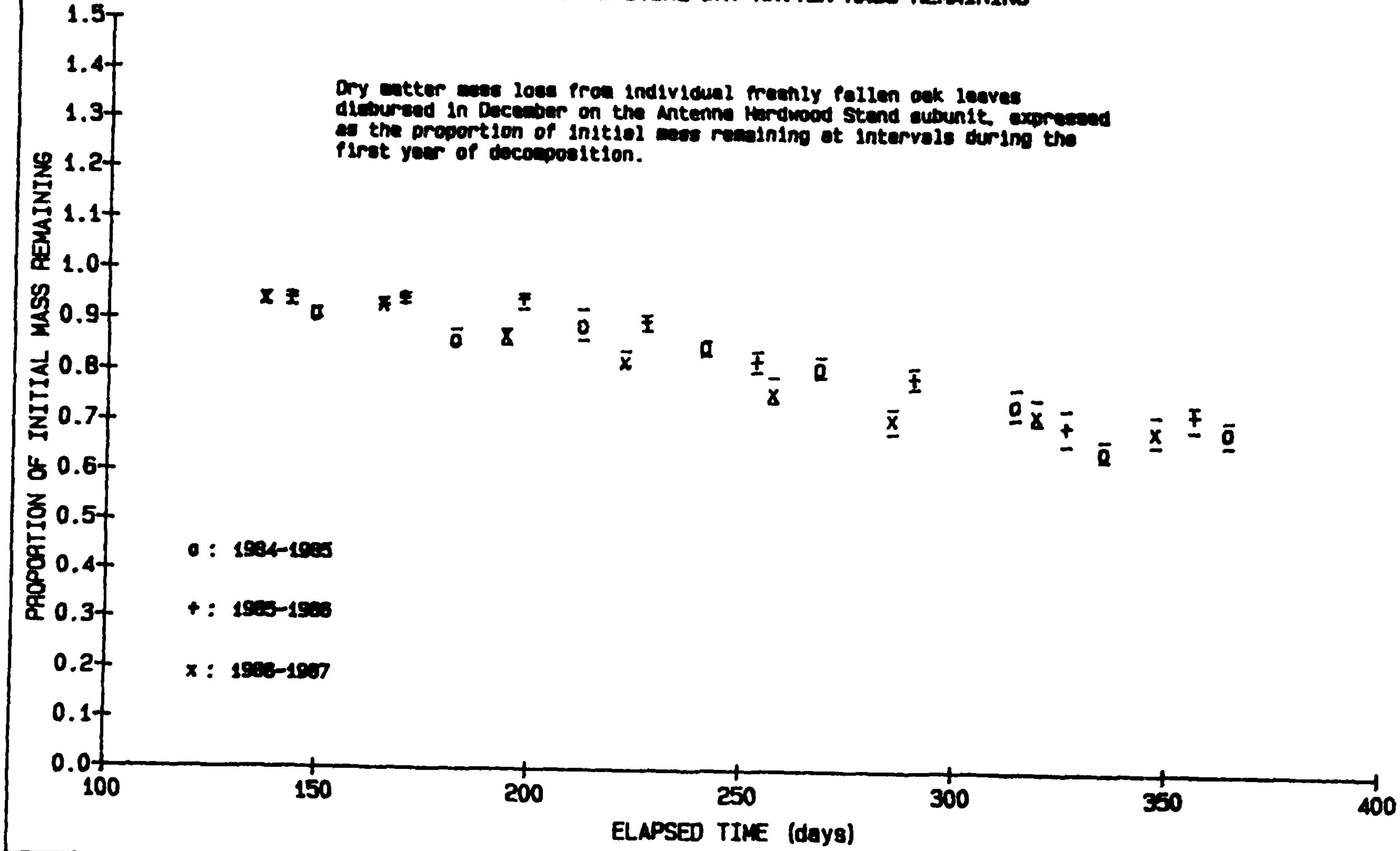
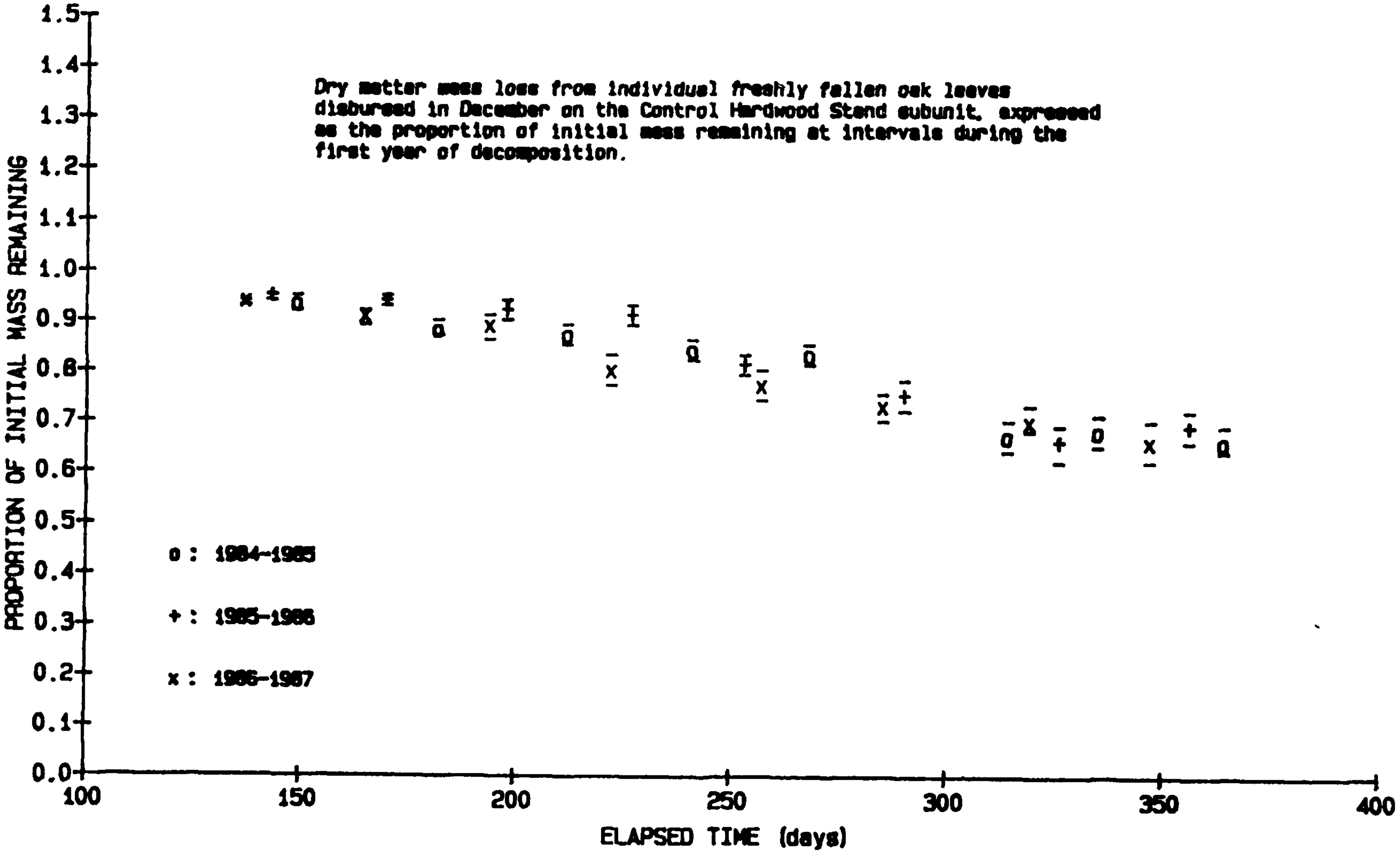


FIGURE 16.

INDIVIDUAL OAK LEAVES, CONTROL HARDWOOD STAND

PROPORTION OF INITIAL DRY MATTER MASS REMAINING



in dry matter mass loss during the 1986-87 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. Figures 10 and 11 present corresponding data for the 1985-86 and 1984-85 studies, respectively. As with the individual pine fascicles, the similarity in oak leaf decomposition among plantation and hardwood stand subunits is encouraging.

Figure 12 presents comparisons of monthly progress in dry matter mass loss during the 1984-85, 1985-86, and 1986-87 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 13 through 16 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands. The significant differences detected by ANOVA are apparent, with the 1986-87 study in the plantations standing out especially.

Individual Maple Leaves

Tables 17 and 18 present ANOVA tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 19 and 20 present comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANOVAs, respectively.

Individual maple leaves placed in the ground plantation decomposed faster than those placed either in the antenna or control plantation; those placed in the control plantation decomposed slowest. Samples placed in the control hardwood stand decomposed faster than those in the antenna hardwood stand. Comparing years in the plantations, no significant difference was detected between 1985 and 1986, the only two years in which individual maple leaves have been included. In hardwood stands, 1985 samples decomposed faster than 1986 samples. Monthly progress in the plantations occurred largely during May, June and September.

Table 17. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual maple leaves in the three plantation subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	15	13.19		45.99	0.0001	0.46
Year	1		0.02	1.07	0.3015	
Month	6		11.72	102.17	0.0001	
Plantation	2		0.83	21.62	0.0001	
Location	6		0.50	4.35	0.0002	
Error	824	15.76				
Corrected Total	839	28.95				

Table 18. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual maple leaves in the two hardwood stand subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	13	5.83		42.26	0.0001	0.46
Year	1		1.45	136.86	0.0001	
Month	7		4.15	55.88	0.0001	
Hardwood Stand	1		0.10	9.05	0.0027	
Location	4		0.06	1.49	0.2035	
Error	648	6.88				
Corrected Total	661	12.71				

Table 19. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 17.

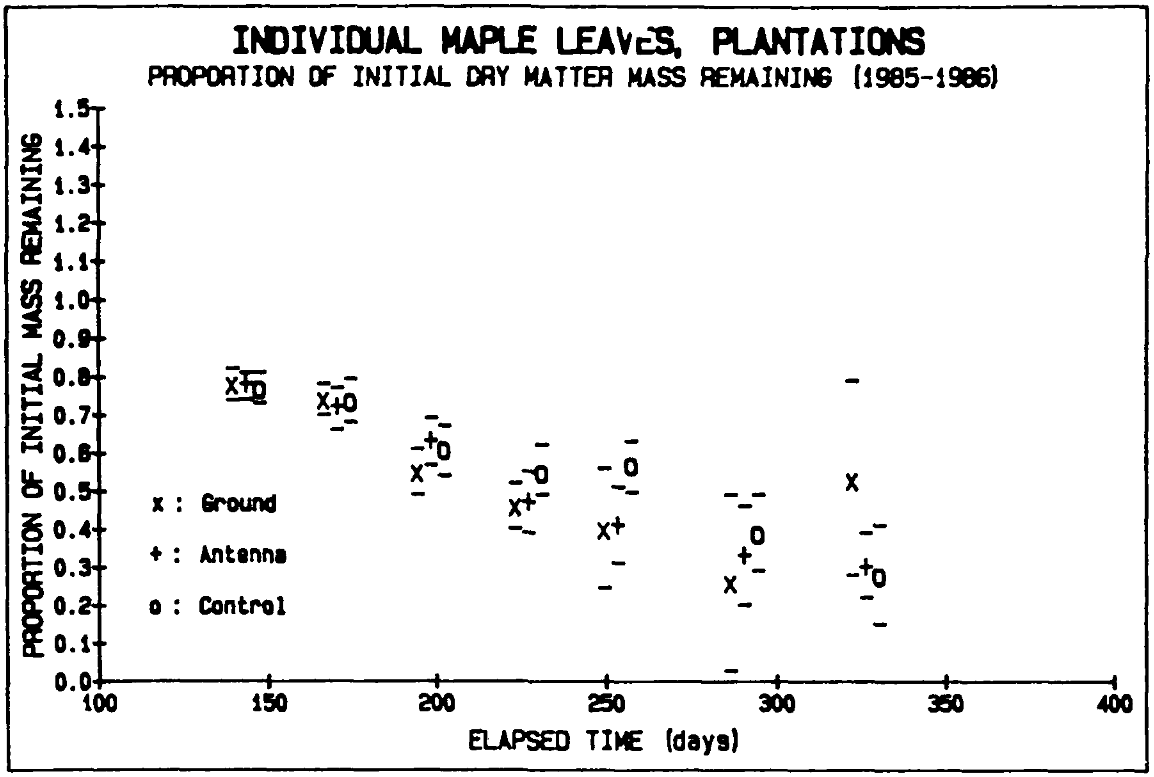
Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year						5				
1985	0.82	0.006	1.43	1985						
1986	0.83	0.010	2.36	1986						
Month					1	2	3	4	5	6
May	1.02	0.013	2.50	May						
June	0.95	0.013	2.68	June	*					
July	0.86	0.013	2.96	July	*	*				
August	0.81	0.013	3.15	Aug	*	*				
September	0.79	0.013	3.23	Sept	*	*	*			
October	0.68	0.013	3.75	Oct	*	*	*	*	*	
November	0.68	0.014	4.04	Nov	*	*	*	*	*	
Plantation							G		A	
Ground	0.79	0.009	2.23	Ground						
Antenna	0.82	0.009	2.15	Antenna			*			
Control	0.87	0.009	2.03	Control			*		*	

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 20. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 18.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year							5				
1985	0.89	0.005	1.10	1985							
1986	0.99	0.008	1.58	1986			*				
Month					1	2	3	4	5	6	7
May	1.06	0.012	2.22	May							
June	1.01	0.011	2.13	June							
July	1.01	0.011	2.13	July							
August	0.96	0.011	2.25	Aug	*	*	*				
September	0.93	0.011	2.32	Sept	*	*	*				
October	0.86	0.011	2.51	Oct	*	*	*	*	*		
November	0.82	0.011	2.63	Nov	*	*	*	*	*		
December	0.87	0.012	2.70	Dec	*	*	*	*	*		
Hardwood Stand								A			
Antenna	0.95	0.006	1.24	Antenna							
Control	0.93	0.006	1.26	Control				*			

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.


INDIVIDUAL MAPLE LEAVES, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control

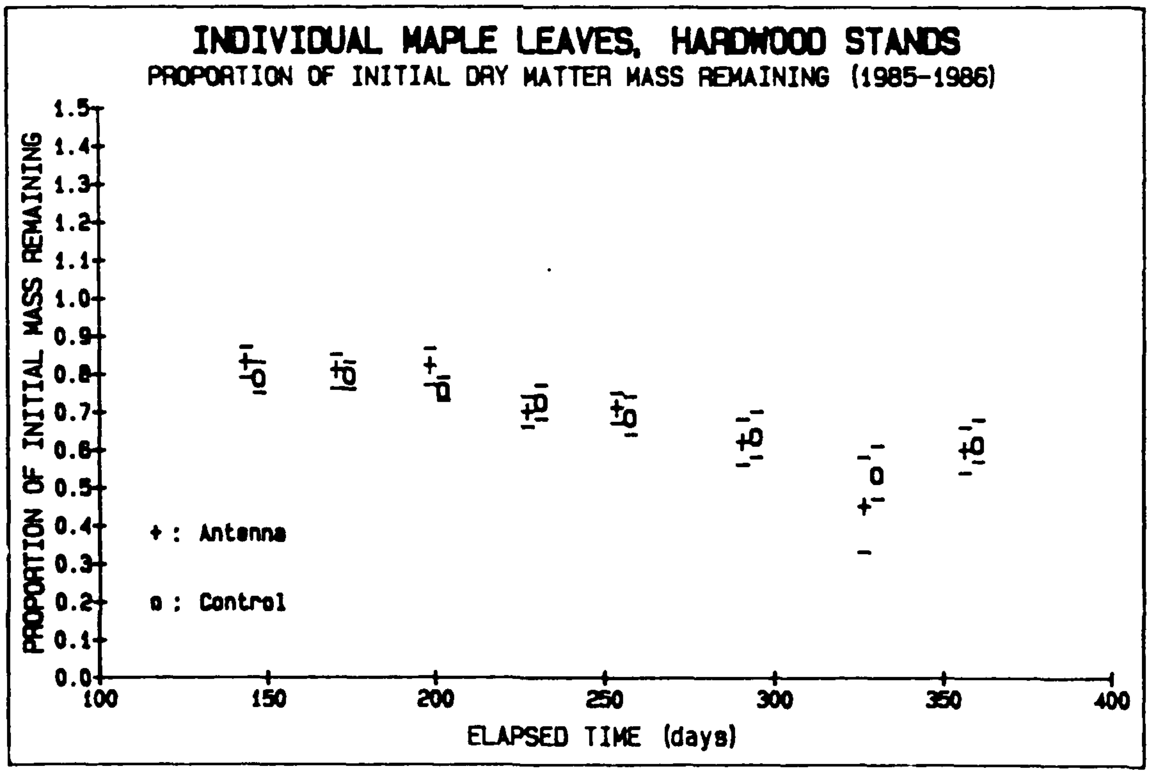

INDIVIDUAL MAPLE LEAVES, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
+ : Antenna
o : Control

FIGURE 17.

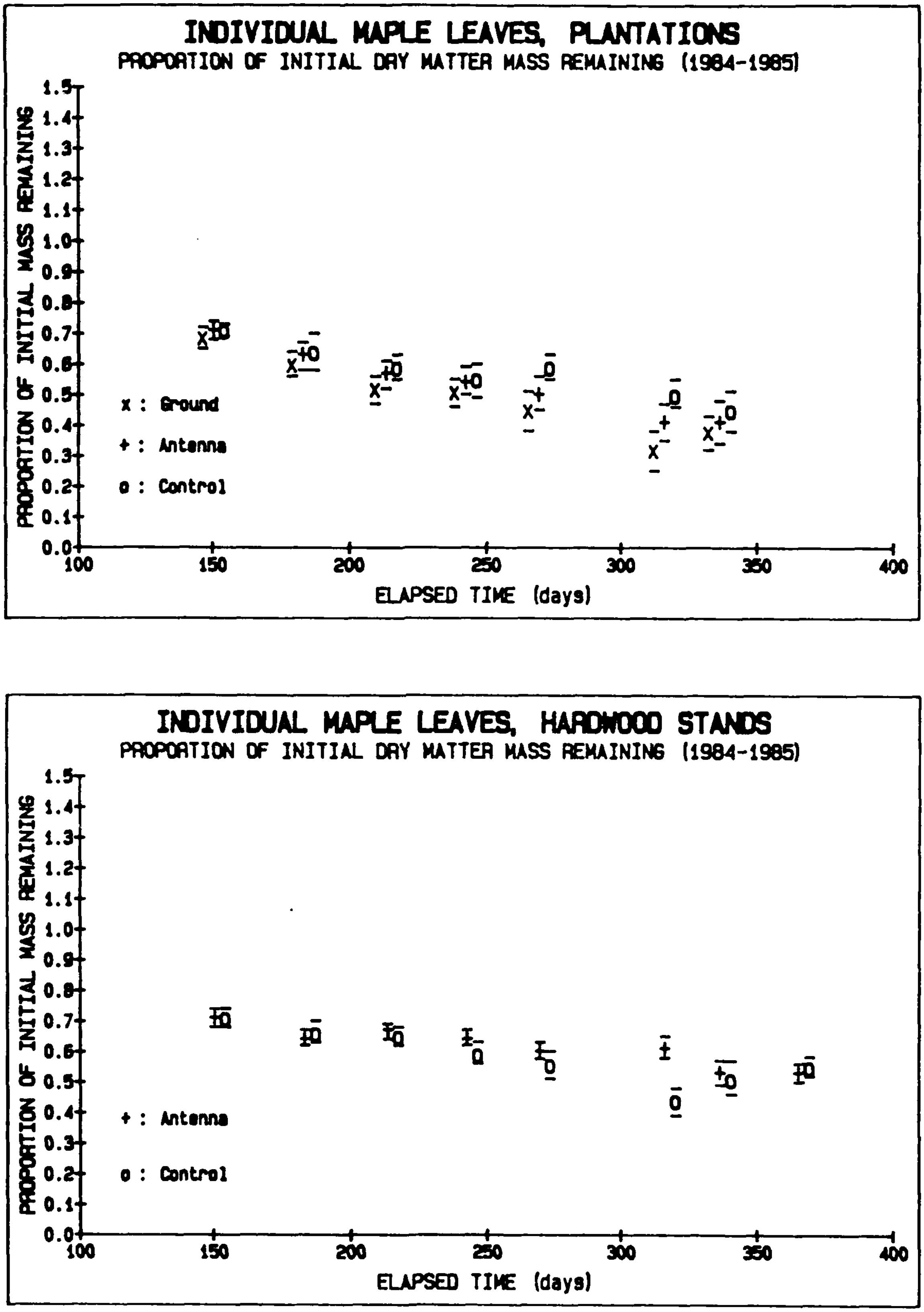

INDIVIDUAL MAPLE LEAVES, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
x : Ground
+ : Antenna
o : Control
ELAPSED TIME (days)
INDIVIDUAL MAPLE LEAVES, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
+ : Antenna
o : Control
ELAPSED TIME (days)

FIGURE 18.

FIGURE 19. INDIVIDUAL MAPLE LEAVES, GROUND PLANTATION

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

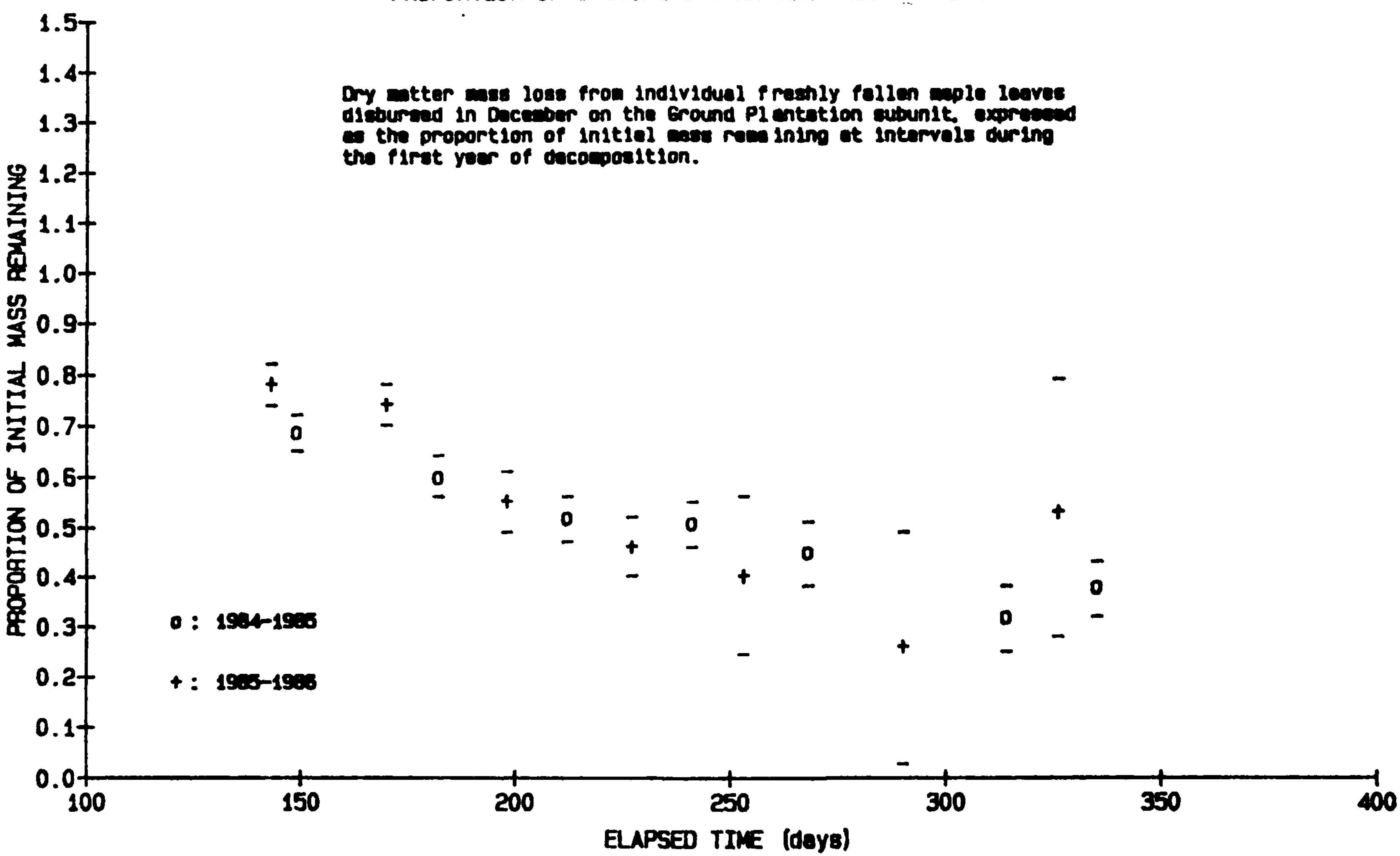


FIGURE 20.

INDIVIDUAL MAPLE LEAVES, ANTENNA PLANTATION

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

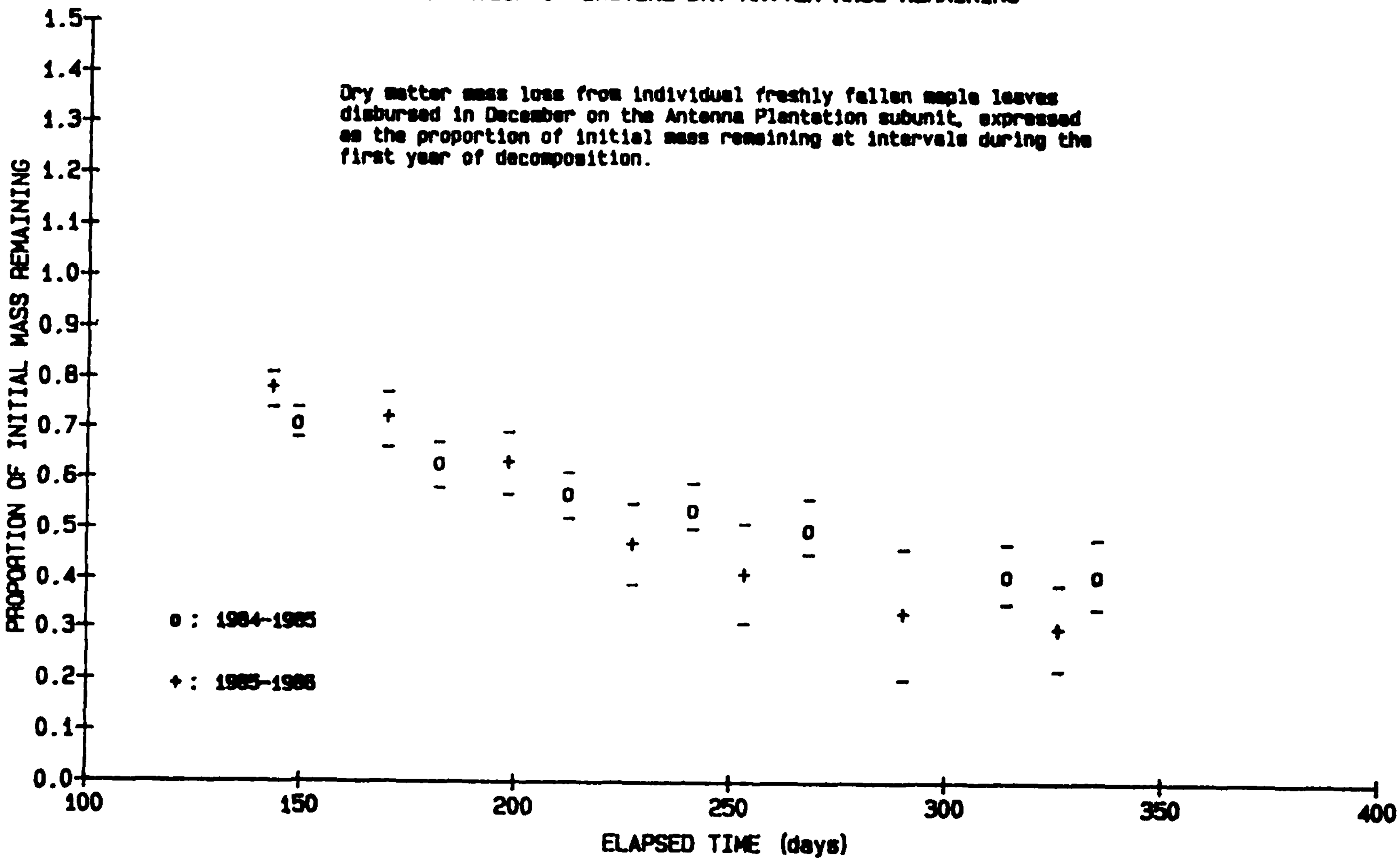
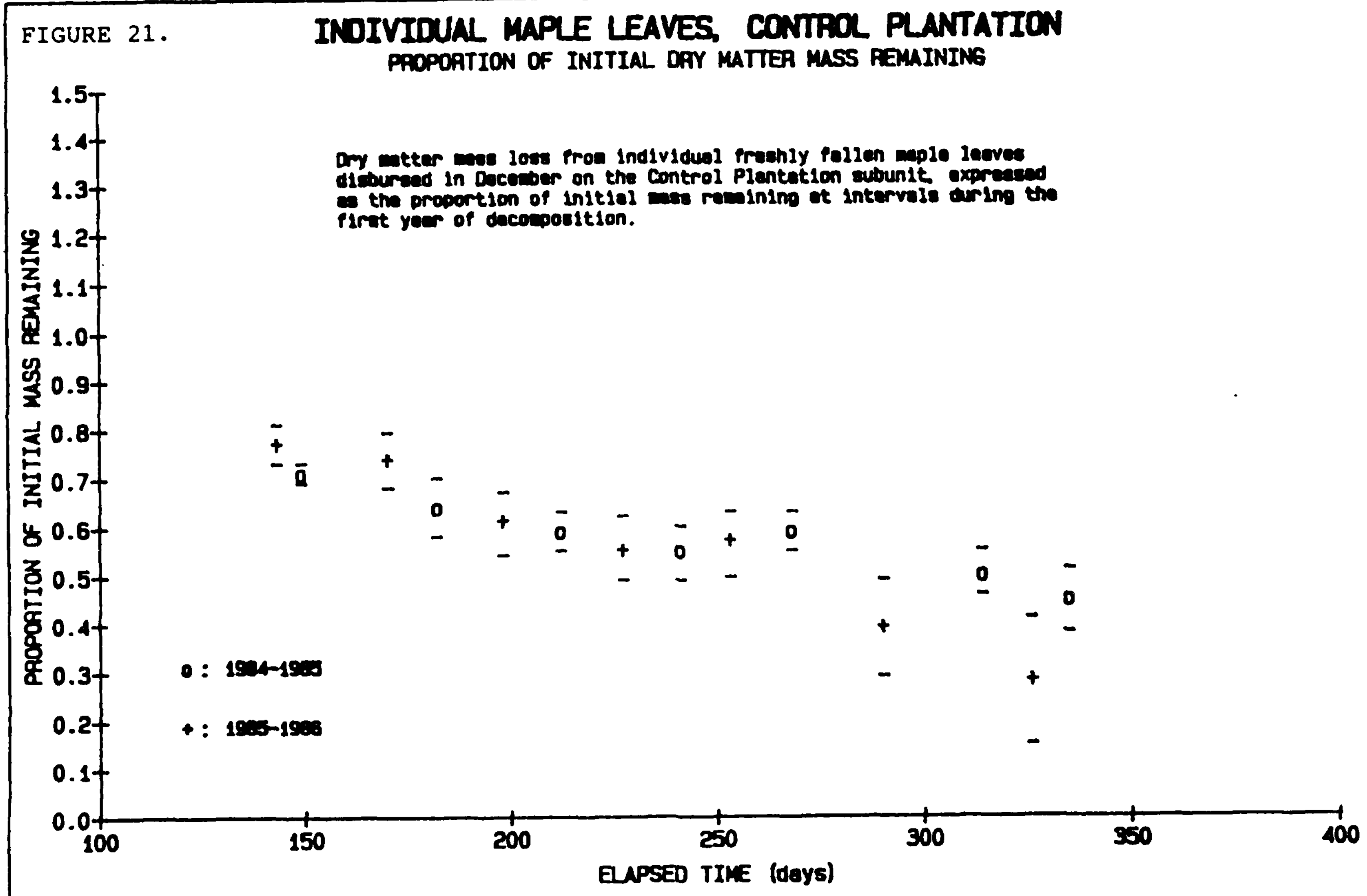


FIGURE 21.



INDIVIDUAL MAPLE LEAVES, CONTROL PLANTATION
PROPORTION OF INITIAL DRY MATTER MASS REMAINING
Dry matter mass loss from individual freshly fallen maple leaves disbursed in December on the Control Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
o : 1984-1985
+ : 1985-1986
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 22. **INDIVIDUAL MAPLE LEAVES, ANTENNA HARDWOOD STAND**

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

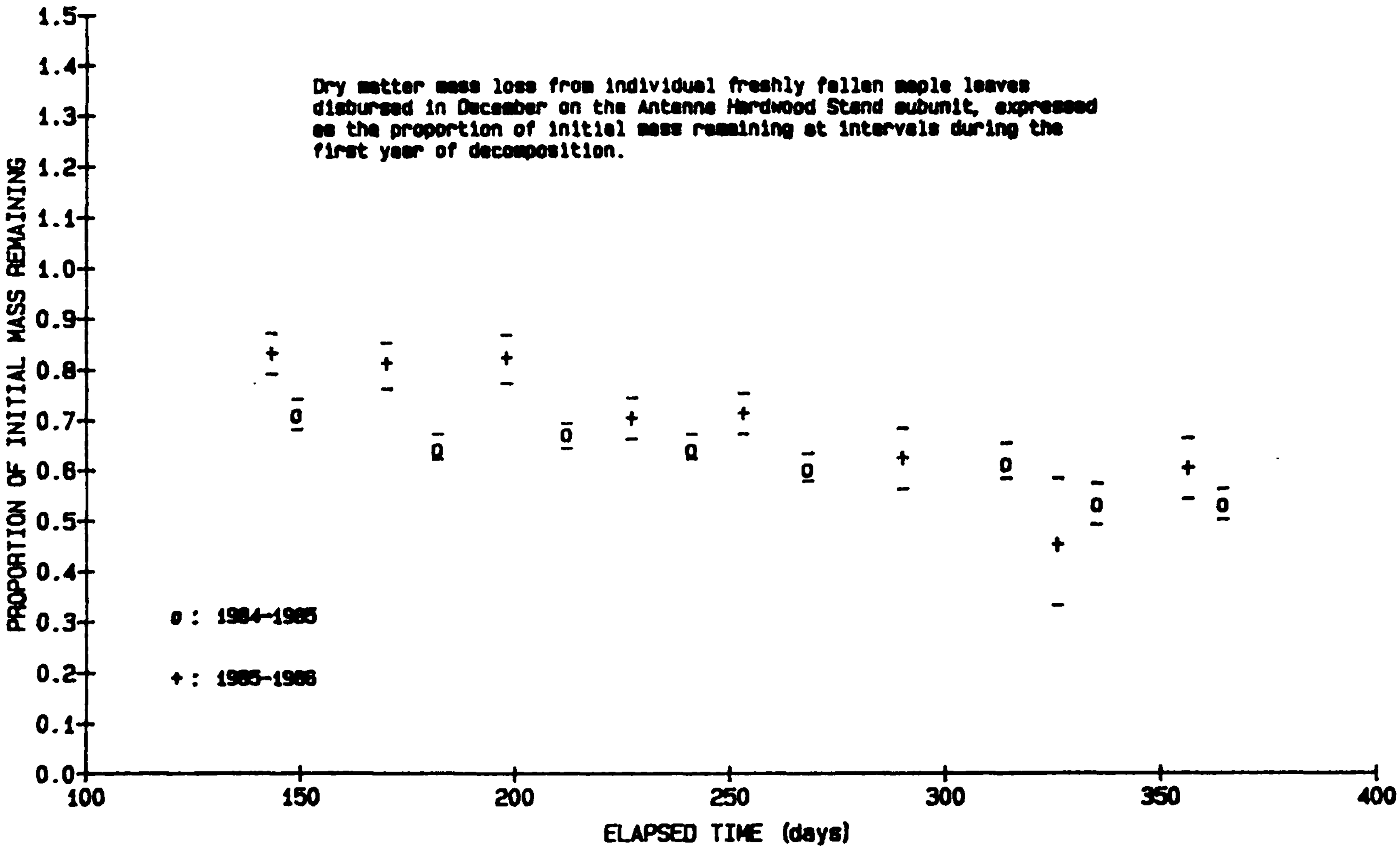
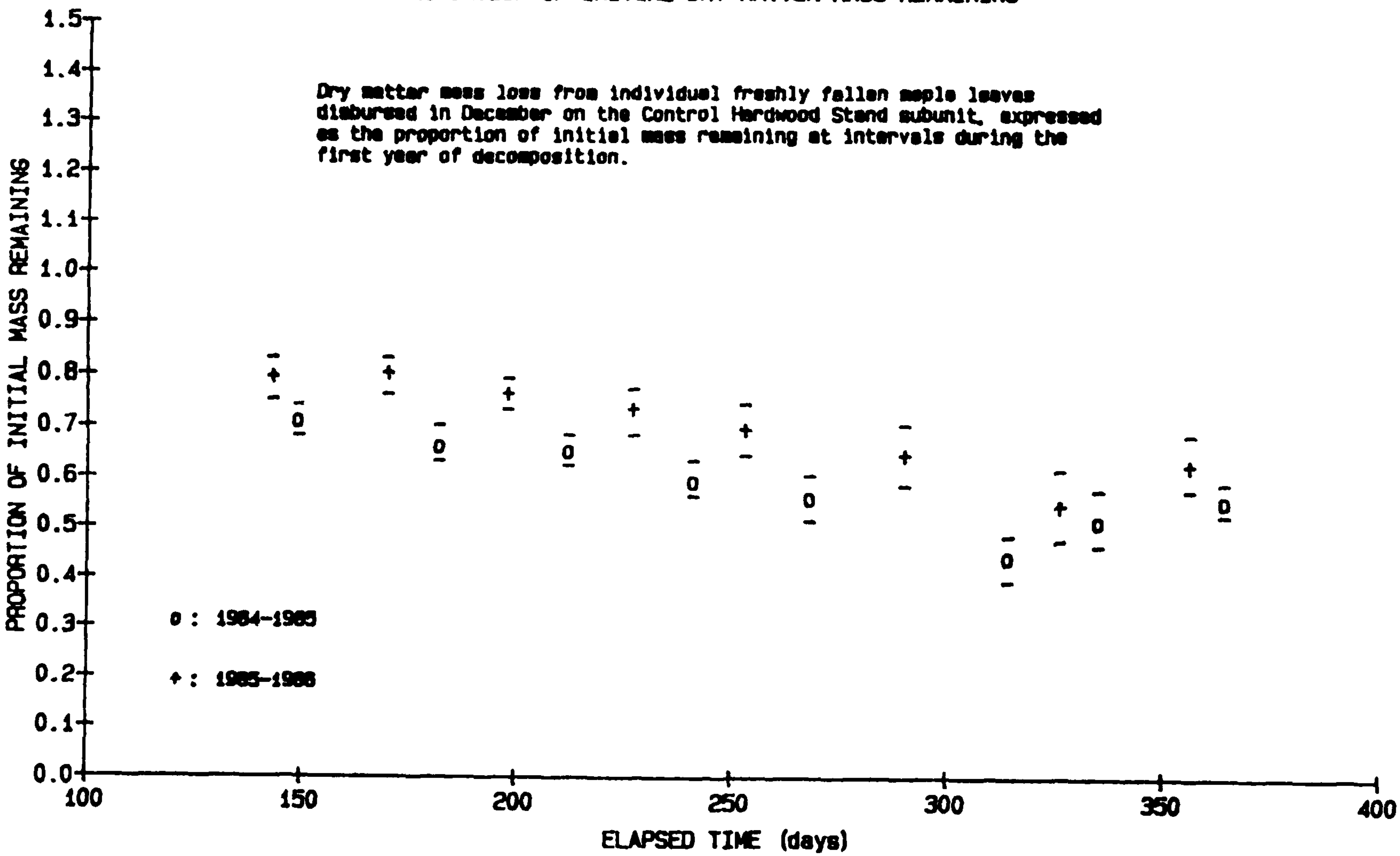


FIGURE 23. **INDIVIDUAL MAPLE LEAVES, CONTROL HARDWOOD STAND**

PROPORTION OF INITIAL DRY MATTER MASS REMAINING



Significant monthly progress in the hardwood stands occurred during July and September. Again, detectable differences were low, well below 5 percent for yearly, monthly and subunit mean values.

Figures 17a and 17b present comparisons of monthly progress in dry matter mass loss during the 1985-86 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. Figure 18 presents corresponding data for the 1984-85 study. The greater variability in maple leaf data obtained from the plantation subunits, relative to the pine and oak data, especially during the 1985-86 study, is clearly apparent. The similarity in maple leaf decomposition among hardwood stand subunits is encouraging. The significant difference between hardwood stand subunits detected by ANOVA is just noticeable from the figures.

Figure 19 presents comparisons of monthly progress in dry matter mass loss during the 1984-85 and 1985-86 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 20 through 23 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands. The greater variability in maple leaf decomposition than that noted for pine or oak is clearly depicted in these figures. It appears that this variability may obscure what appears to have been faster decomposition during 1986 than during 1985 in the plantation subunits.

Individual Filter Paper Disks

Tables 21 and 22 present the ANOVA tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 23 and 24 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANOVAs, respectively.

Filter paper disks placed in the control plantation decom-

Table 21. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual Whatman No. 1 filter paper disks in the three plantation subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	76	10.03		1.69	0.0017	0.36
Year	0		0.00	-.--	-.----	
Month	6		3.25	6.92	0.0001	
Plantation	2		1.26	8.05	0.0004	
Location	68		6.01	1.13	0.2520	
Error	228	17.83				
Corrected Total	304	27.86				

Table 22. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual Whatman No. 1 filter paper disks in the two hardwood stand subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	53	7.16		2.16	0.0001	0.39
Year	2		0.00	-.--	-.----	
Month	7		3.14	8.39	0.0001	
Hardwood Stand	1		0.50	7.94	0.0054	
Location	46		4.35	1.51	0.0298	
Error	181	11.31				
Corrected Total	234	18.47				

Table 23. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 21.

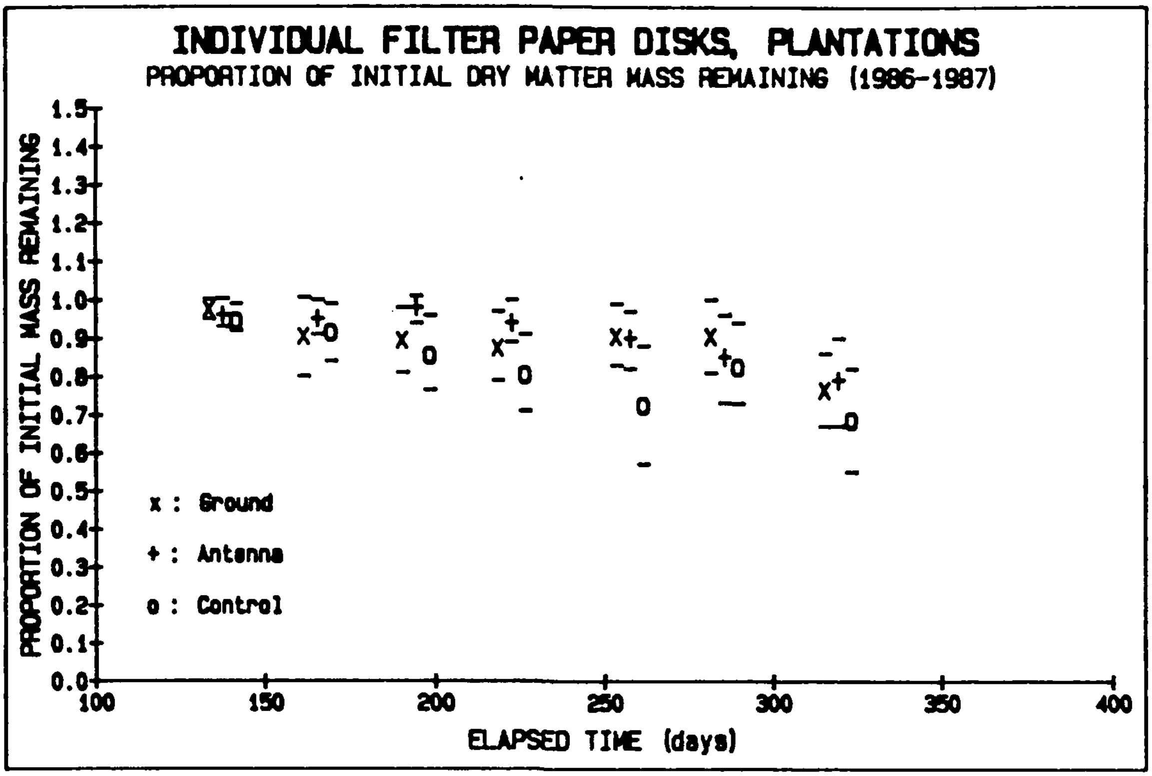
Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year										
1987	1.18	0.019	3.16							
Month					1	2	3	4	5	6
May	1.40	0.048	6.72	May						
June	1.19	0.053	8.73	June	*					
July	1.20	0.050	8.17	July	*					
August	1.16	0.046	7.77	Aug	*					
September	1.13	0.045	7.81	Sept	*					
October	1.16	0.045	7.60	Oct	*					
November	1.02	0.037	7.11	Nov	*	*	*	*		*
Plantation							G		A	
Ground	1.20	0.034	5.55	Ground						
Antenna	1.26	0.034	5.29	Antenna						
Control	1.09	0.027	4.86	Control			*		*	

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

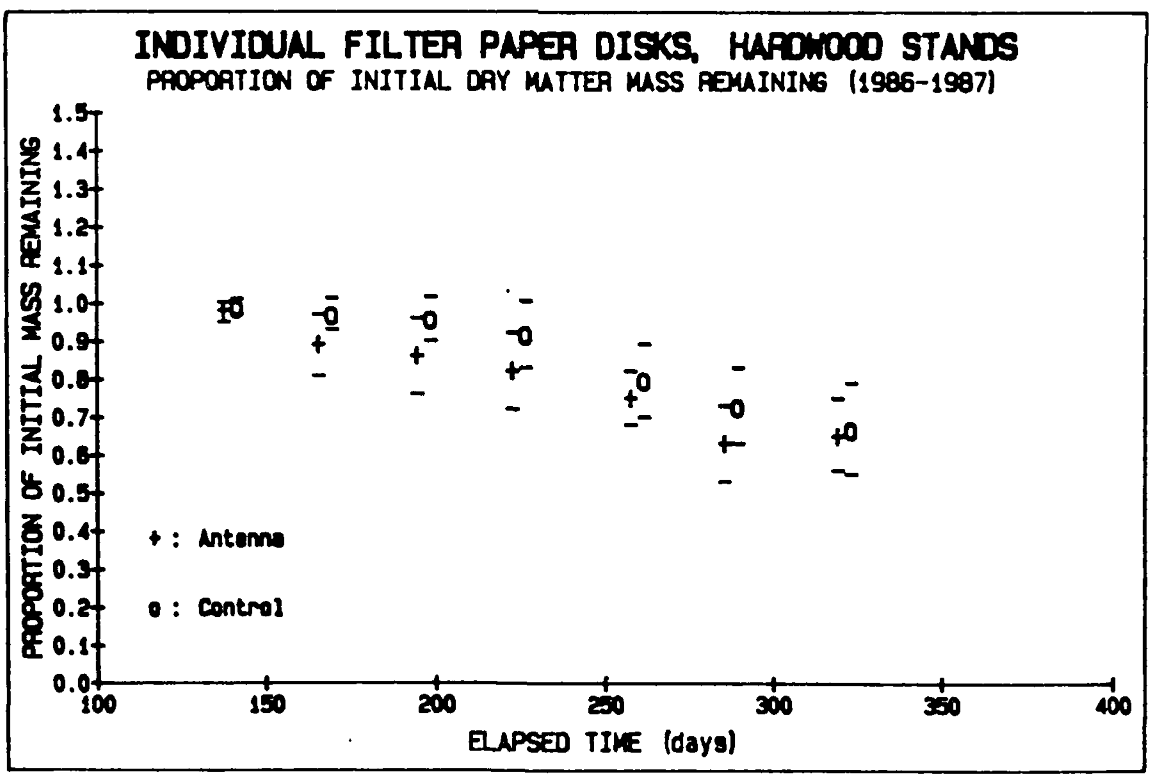
Table 24. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 22.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year										
1987	1.15	0.019	3.24							
Month					1	2	3	4	5	6
May	1.38	0.069	9.80	May						
June	1.27	0.051	7.87	June						
July	1.15	0.055	9.37	July	*					
August	1.17	0.049	8.21	Aug	*					
September	1.11	0.037	6.53	Sept	*	*				
October	0.99	0.037	7.33	Oct	*	*	*	*	*	
November	0.97	0.037	7.48	Nov	*	*	*	*	*	
Hardwood Stand								A		
Antenna	1.10	0.024	4.28	Antenna						
Control	1.20	0.027	4.41	Control				*		

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.



INDIVIDUAL FILTER PAPER DISKS, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1986-1987)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
x : Ground
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)



INDIVIDUAL FILTER PAPER DISKS, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1986-1987)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 24.

posed faster than those in the ground or antenna plantations; the opposite was the case between the control and antenna hardwood stand subunits. Filter paper disks were used in the 1986-87 study only. Monthly progress occurred largely during May and October in the plantations, and during May and September in the hardwood stands. Detectable differences were approximately 3 percent for yearly means, less than 10 percent for monthly means, and 4 to 6 percent for subunit means. Filter paper disks do not appear to represent an improvement over individual maple leaves. Neither filter paper disks nor individual maple leaves were included in the 1987-88 study.

Figures 24a and 24b present comparisons of monthly progress in dry matter mass loss during the 1986-87 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. The variability of the filter paper data is comparable to that for maple in the plantations and greater than that for maple in the hardwood stand subunits. The significant differences among plantations and between hardwood stands are nevertheless noticeable.

ANOVA Results - Bulk Leaf Litter Samples

Bulk Pine Needle Litter

Tables 25 and 26 present the ANOVA tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 27 and 28 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANOVAs.

Bulk pine needles decomposed faster in the ground and control plantations than in the antenna plantation. No difference was detected between the control and antenna hardwood stands. Comparing years in the plantations, 1985 samples decomposed fastest and 1987 samples slowest; in the hardwood stands, 1985 samples decomposed faster than either 1986 or 1987 samples. Sig-

Table 25. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk pine needle samples in the three plantation subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	16	3.53		181.35	0.0001	0.89
Year	2		0.16	65.89	0.0001	
Month	6		3.29	451.16	0.0001	
Plantation	2		0.06	25.27	0.0001	
Location	6		0.01	1.58	0.1509	
Error	362	0.44				
Corrected Total	378	3.97				

Table 26. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk pine needle samples in the two hardwood stand subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	14	3.20		232.79	0.0001	0.92
Year	2		0.16	80.42	0.0001	
Month	7		3.04	443.19	0.0001	
Hardwood Stand	1		0.00	1.82	0.1788	
Location	4		0.00	0.82	0.5124	
Error	273	0.27				
Corrected Total	287	3.46				

Table 27. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 25.

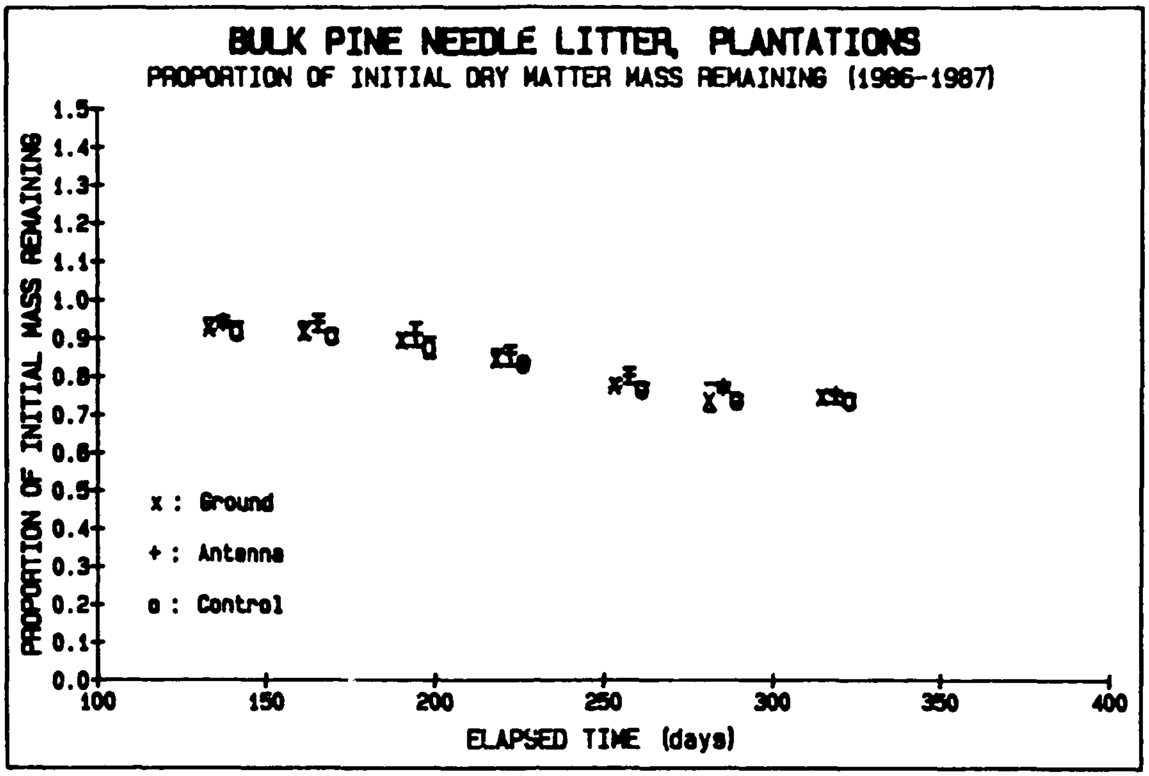
Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6				
1985	1.12	0.003	0.52	1985						
1986	1.15	0.003	0.51	1986	*					
1987	1.17	0.003	0.50	1987	*	*				
Month					1	2	3	4	5	6
May	1.28	0.005	0.77	May						
June	1.24	0.005	0.79	June	*					
July	1.21	0.005	0.81	July	*	*				
August	1.16	0.005	0.84	Aug	*	*	*			
September	1.09	0.005	0.90	Sept	*	*	*	*		
October	1.04	0.005	0.94	Oct	*	*	*	*	*	
November	1.02	0.005	0.96	Nov	*	*	*	*	*	*
Plantation					G	A				
Ground	1.14	0.003	0.52	Ground						
Antenna	1.16	0.003	0.51	Antenna	*					
Control	1.14	0.003	0.52	Control		*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Tukey's H.S.D.

Table 28. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 26.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6					
1985	1.09	0.003	0.54	1985							
1986	1.15	0.003	0.51	1986	*						
1987	1.14	0.003	0.52	1987	*						
Month					1	2	3	4	5	6	7
May	1.29	0.005	0.76	May							
June	1.24	0.005	0.79	June	*						
July	1.21	0.005	0.81	July	*	*					
August	1.15	0.005	0.85	Aug	*	*	*				
September	1.08	0.005	0.91	Sept	*	*	*	*			
Octoher	1.03	0.005	0.95	Oct	*	*	*	*	*		
November	1.01	0.005	0.97	Nov	*	*	*	*	*		
December	1.01	0.005	0.97	Dec	*	*	*	*	*		
Hardwood Stand					C						
Antenna	1.13	0.003	0.52	Antenna							
Control	1.12	0.003	0.53	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, Tukey's H.S.D.


BULK PINE NEEDLE LITTER, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1986-1987)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
x : Ground
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

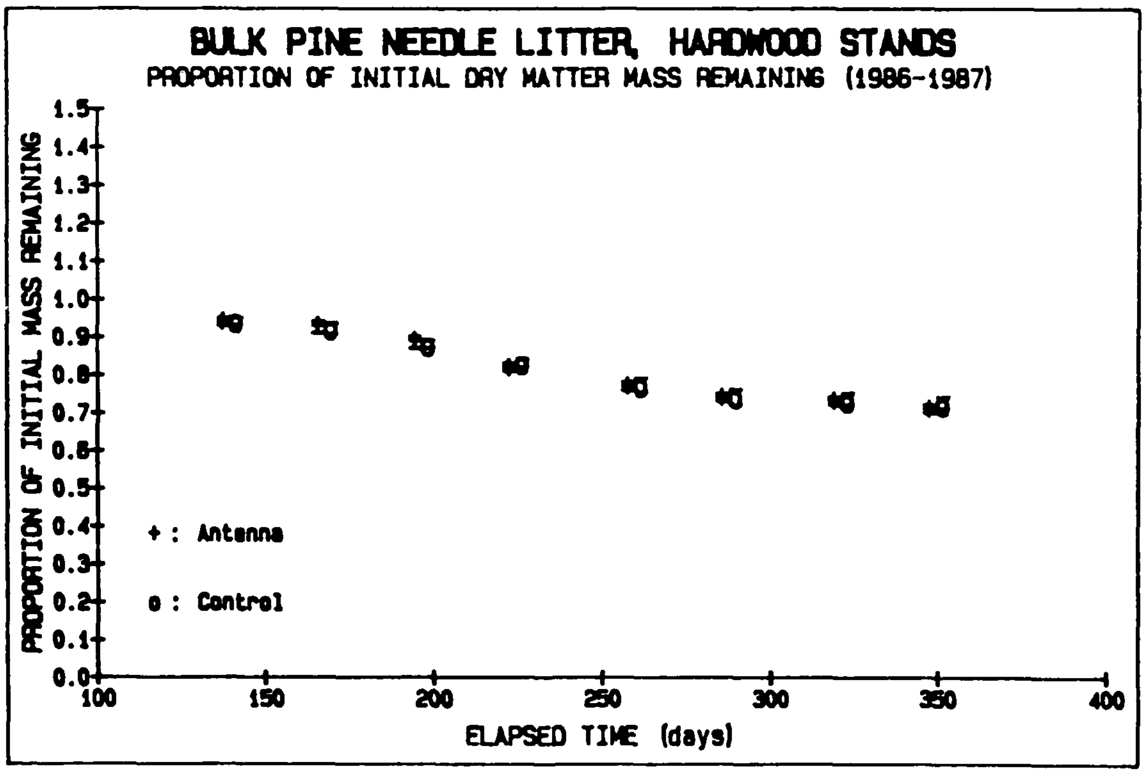
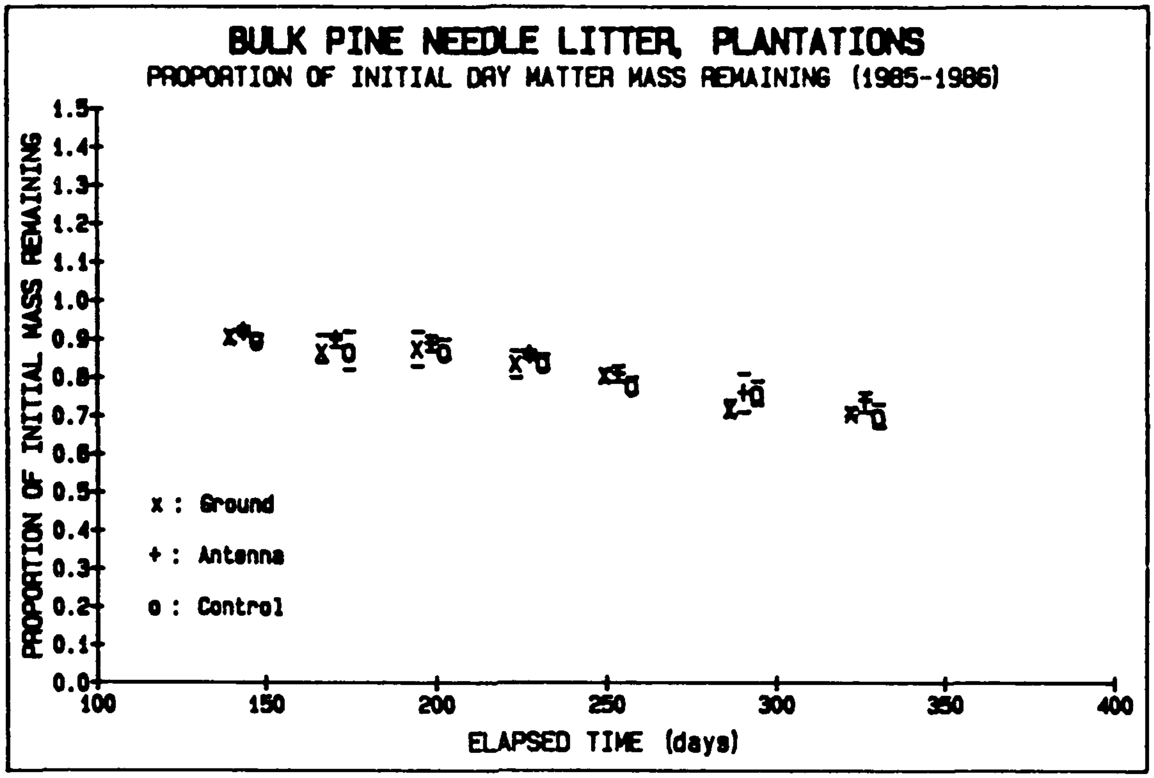

BULK PINE NEEDLE LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1986-1987)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 25.


BULK PINE NEEDLE LITTER, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
100
150
200
250
300
350
400
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control

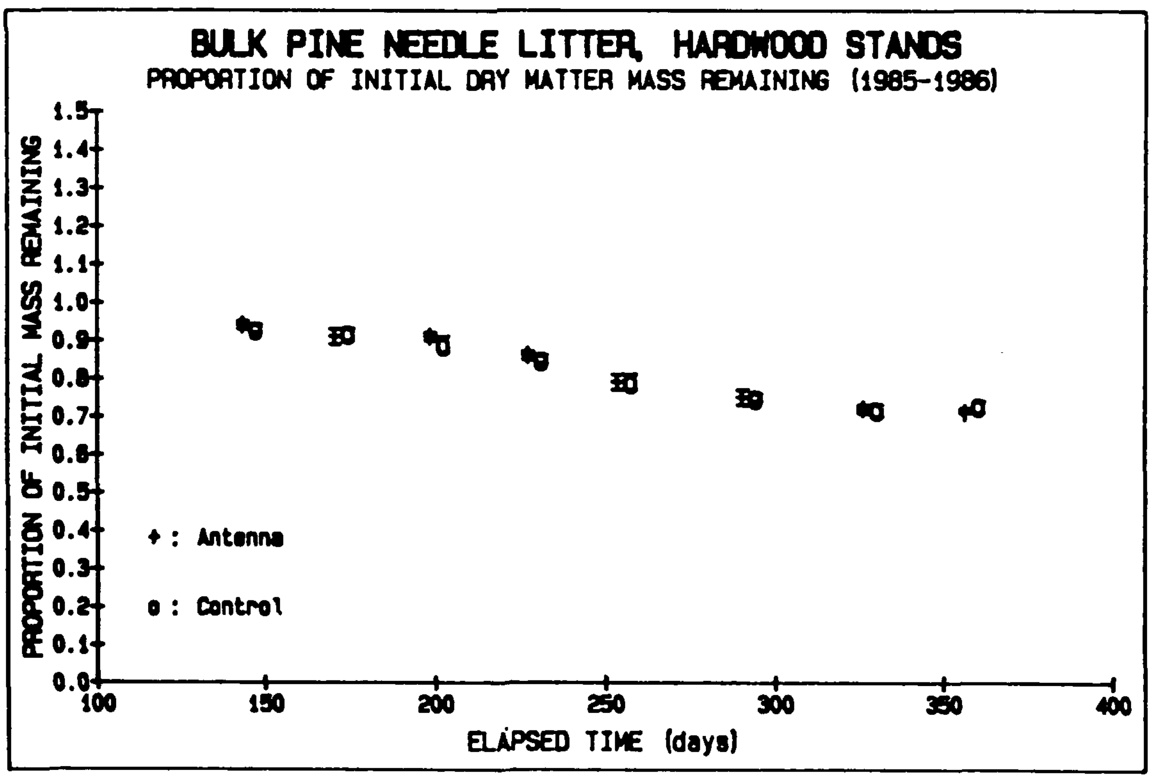
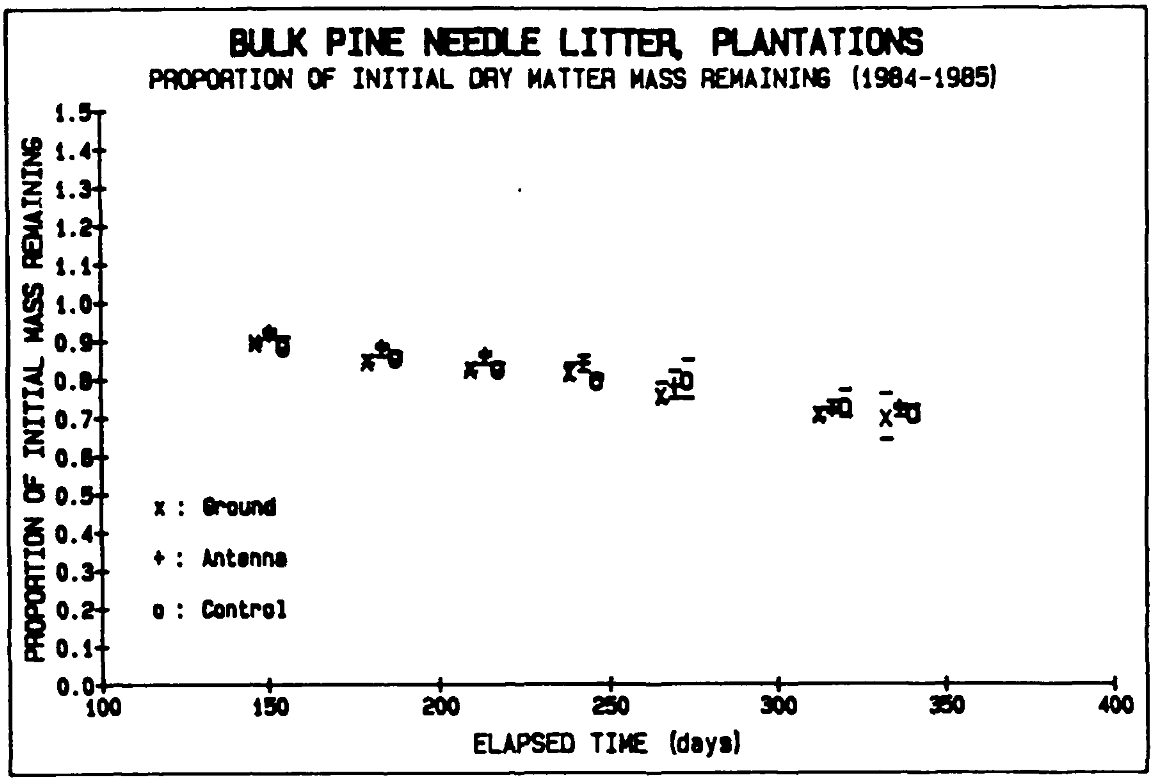
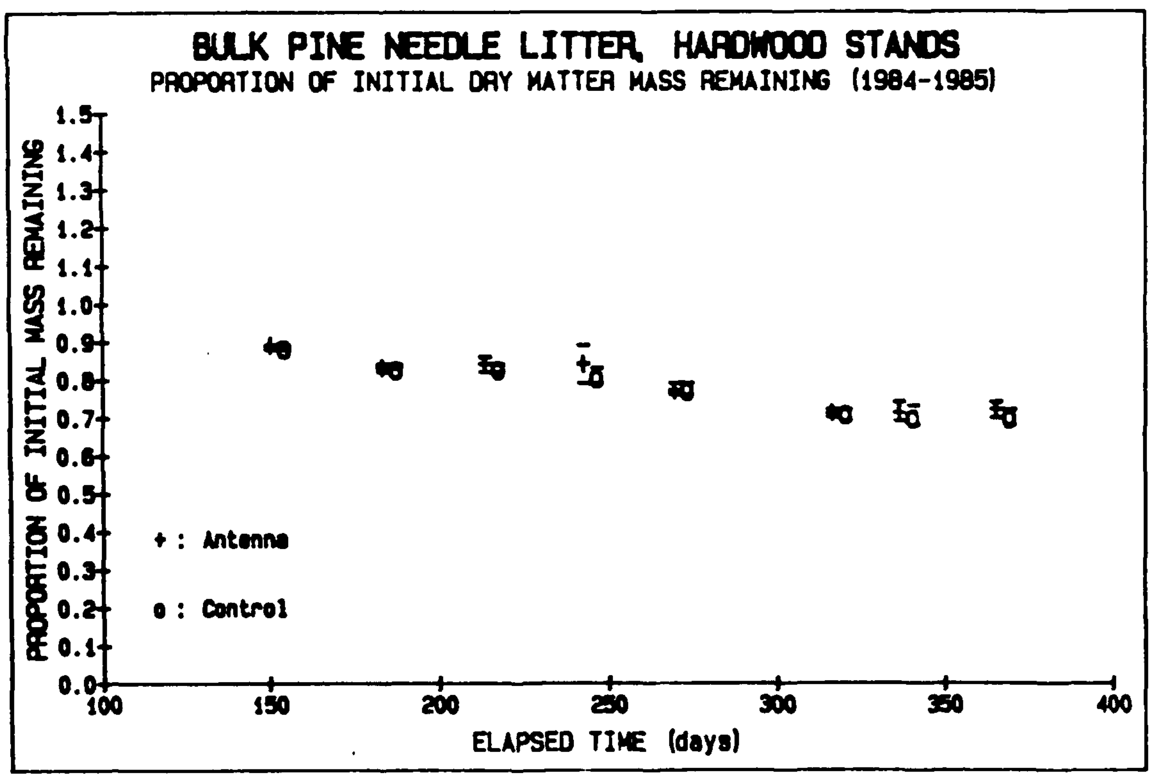

BULK PINE NEEDLE LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
100
150
200
250
300
350
400
ELAPSED TIME (days)
+ : Antenna
o : Control

FIGURE 26.



BULK PINE NEEDLE LITTER, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
100
150
200
250
300
350
400
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control



BULK PINE NEEDLE LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
100
150
200
250
300
350
400
ELAPSED TIME (days)
+ : Antenna
o : Control

FIGURE 27.

FIGURE 28.

BULK PINE LITTER, GROUND PLANTATION

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

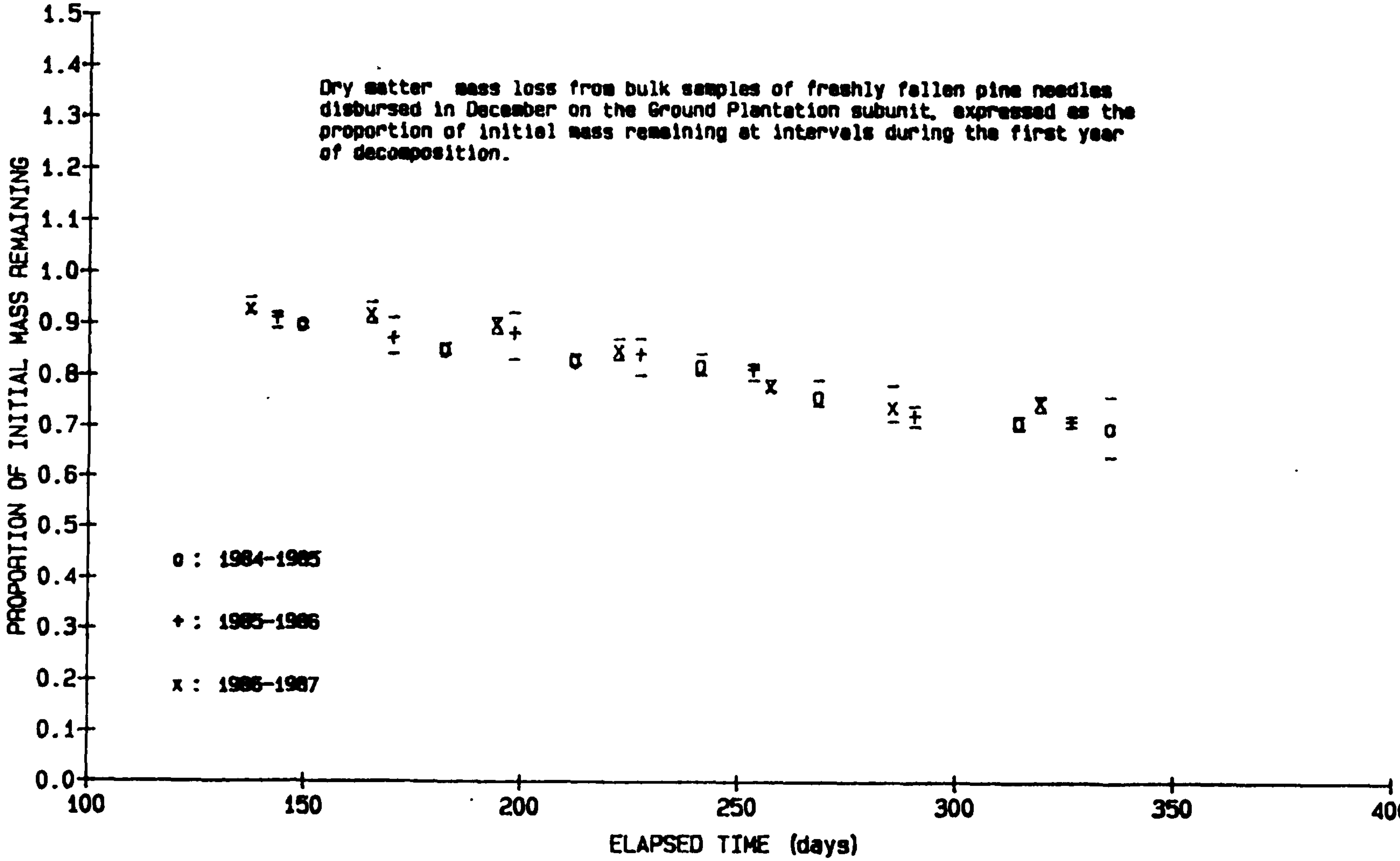


FIGURE 29.

BULK PINE LITTER, ANTENNA PLANTATION

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

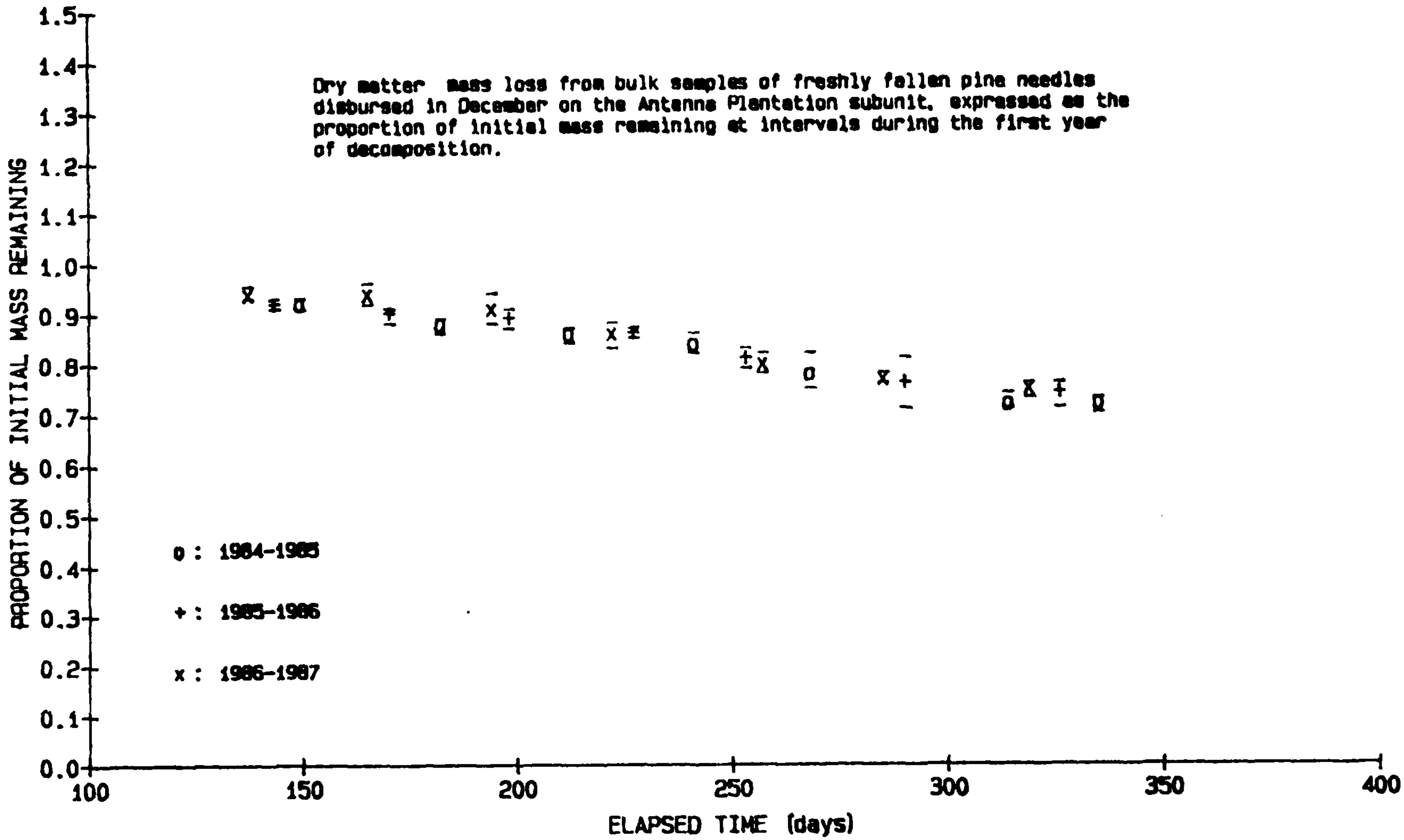


FIGURE 30.

BULK PINE LITTER, CONTROL PLANTATION
PROPORTION OF INITIAL DRY MATTER MASS REMAINING

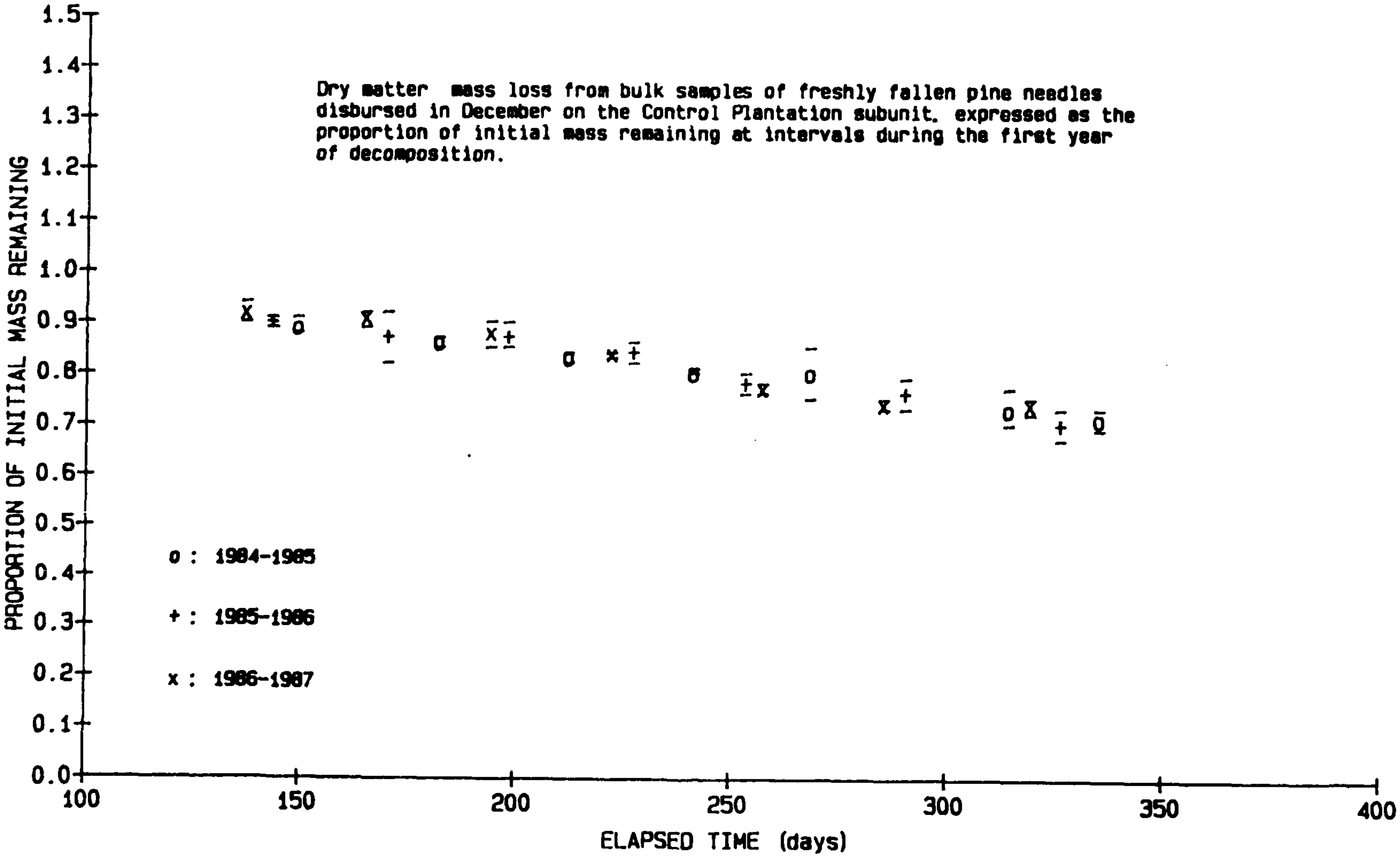


FIGURE 31.

BULK PINE LITTER, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

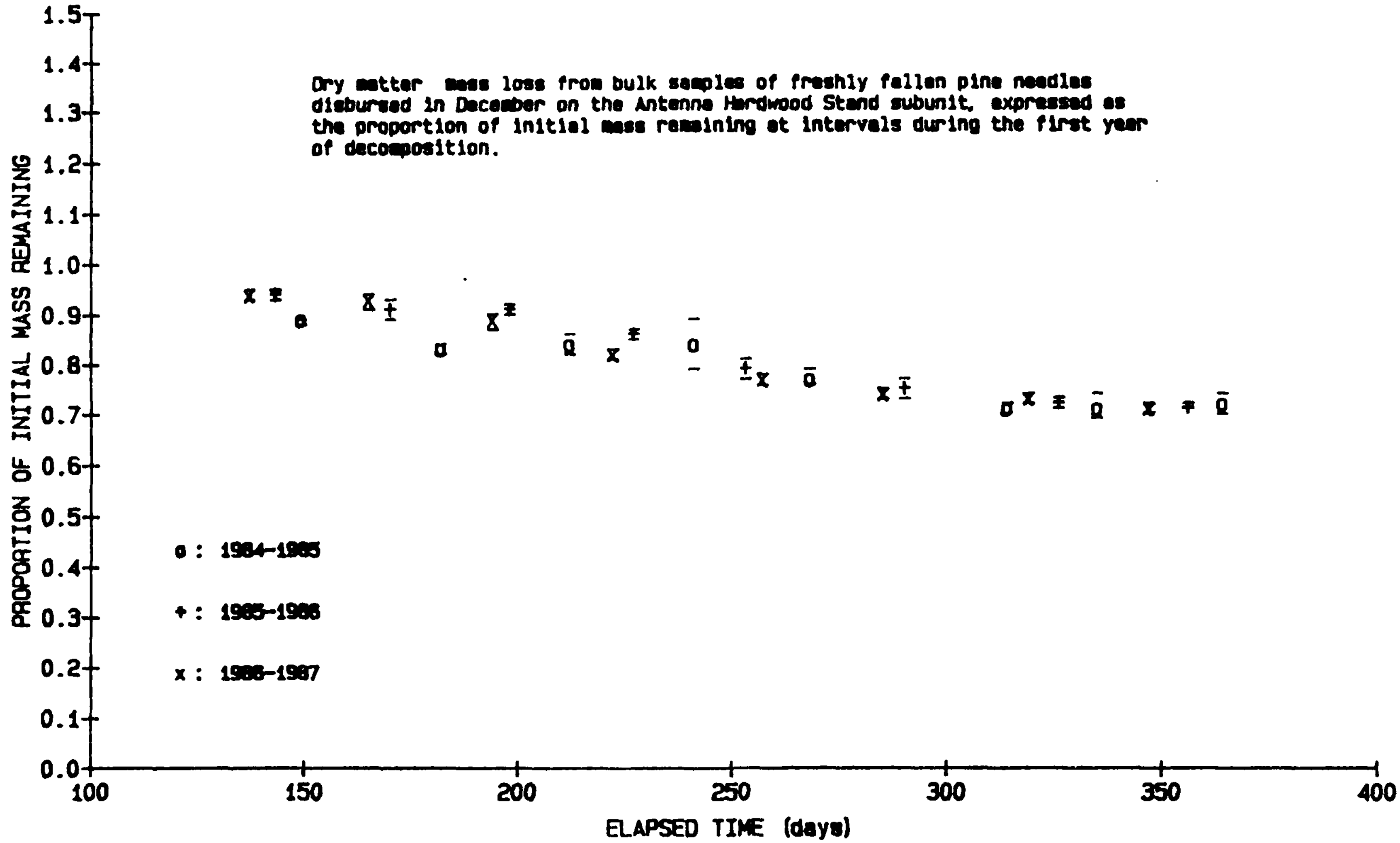
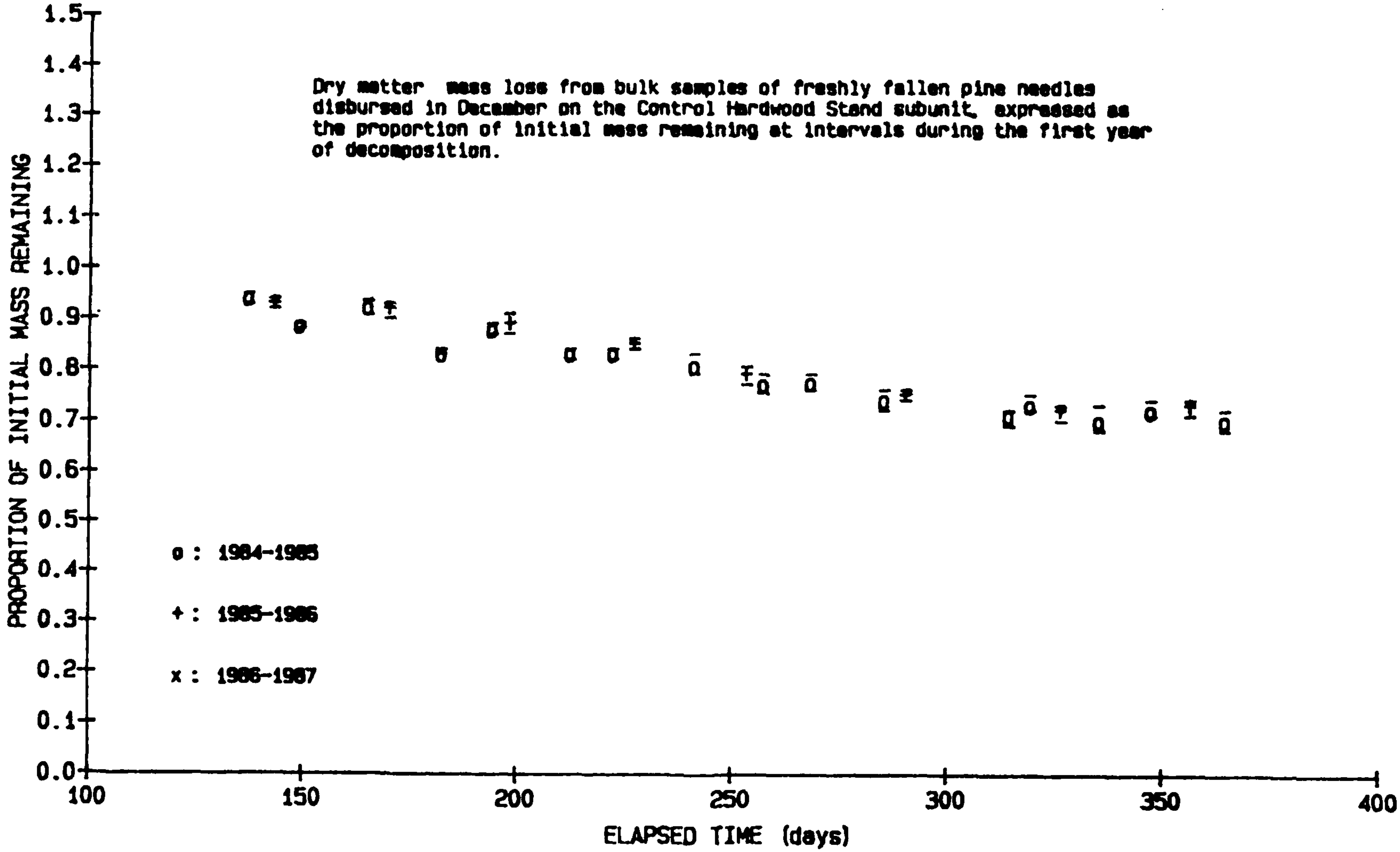


FIGURE 32.

BULK PINE LITTER, CONRTOL HARDWOOD STAND

PROPORTION OF INITIAL DRY MATTER MASS REMAINING



nificant monthly progress occurred in the plantations, while monthly progress in the hardwood stands occurred from May through September. Detectable differences were extremely low, well below 1 percent of the yearly, monthly and subunit mean values. This accounts for some of the very small differences between mean values which are nonetheless significant.

Figures 25a and 25b present comparisons of monthly progress in dry matter mass loss during the 1986-87 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. Figures 26 and 27 present corresponding data for the 1985-86 and 1984-85 studies, respectively. As with the individual pine fascicle samples, the general similarity among plantation and hardwood stand subunits is encouraging, and suggests that ANACOV may explain the differences detected by ANOVA. The significant differences detected between plantation subunits by ANOVA would be difficult to anticipate from the figures alone.

Figure 28 presents comparisons of monthly progress in dry matter mass loss during the 1984-85, 1985-86, and 1986-87 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 29 through 32 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands, respectively. Again, the significant differences detected by ANOVA are small, suggesting that ANACOV may explain them.

Bulk Oak Leaf Litter

Tables 29 and 30 present the ANOVA tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 31 and 32 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANOVAs, respectively.

Table 29. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk oak leaf samples in the three plantation subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r*
Model	16	4.90		81.03	0.0001	0.78
Year	2		0.09	11.89	0.0001	
Month	6		4.76	209.87	0.0001	
Plantation	2		0.04	5.29	0.0054	
Location	6		0.03	1.28	0.2664	
Error	364	1.37				
Corrected Total	380	6.27				

Table 30. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk oak leaf samples in the two hardwood stand subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r*
Model	14	5.06		163.41	0.0001	0.89
Year	2		0.22	50.22	0.0001	
Month	7		4.82	311.17	0.0001	
Hardwood Stand	1		0.04	16.29	0.0001	
Location	4		0.01	0.92	0.4552	
Error	274	0.61				
Corrected Total	288	5.67				

Table 31. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 29.

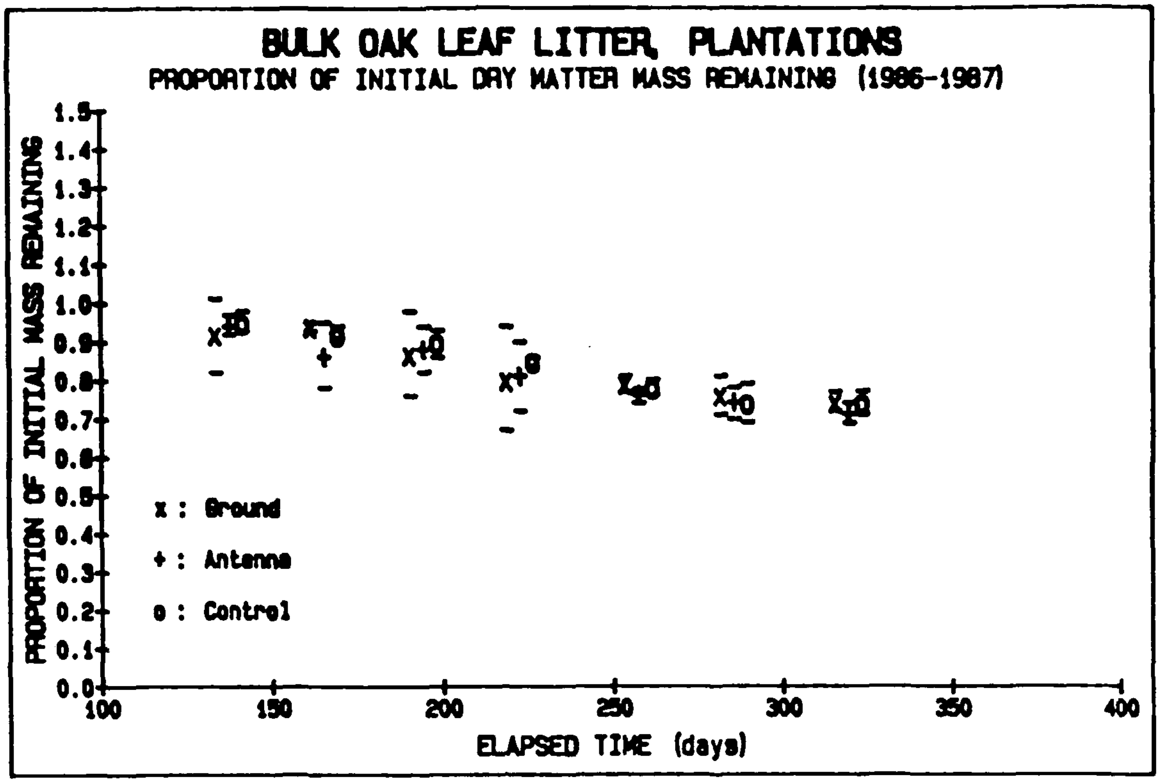
Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year								5	6	
1985	1.13	0.005	0.87	1985						
1986	1.17	0.005	0.84	1986				*		
1987	1.16	0.005	0.84	1987				*		
Month					1	2	3	4	5	6
May	1.31	0.008	1.20	May						
June	1.27	0.008	1.23	June	*					
July	1.22	0.008	1.29	July	*	*				
August	1.16	0.008	1.35	Aug	*	*	*			
September	1.09	0.008	1.44	Sept	*	*	*	*		
October	1.03	0.008	1.52	Oct	*	*	*	*	*	
November	0.99	0.008	1.58	Nov	*	*	*	*	*	*
Plantation							G		A	
Ground	1.14	0.005	0.86	Ground						
Antenna	1.15	0.005	0.85	Antenna						
Control	1.17	0.005	0.84	Control			*			

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 32. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 30.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year									5	6	
1985	1.13	0.005	0.87	1985							
1986	1.20	0.005	0.82	1986					*		
1987	1.17	0.005	0.84	1987					*	*	
Month					1	2	3	4	5	6	7
May	1.33	0.008	1.18	May							
June	1.31	0.008	1.20	June							
July	1.27	0.008	1.23	July	*	*					
August	1.22	0.008	1.29	Aug	*	*	*				
September	1.14	0.008	1.38	Sept	*	*	*	*			
October	1.05	0.008	1.49	Oct	*	*	*	*	*		
November	1.03	0.008	1.52	Nov	*	*	*	*	*		
December	0.97	0.008	1.62	Dec	*	*	*	*	*	*	*
Hardwood Stand								A			
Antenna	1.18	0.004	0.66	Antenna							
Control	1.15	0.004	0.68	Control				*			

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.


BULK OAK LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1986-1987)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
x : Ground
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

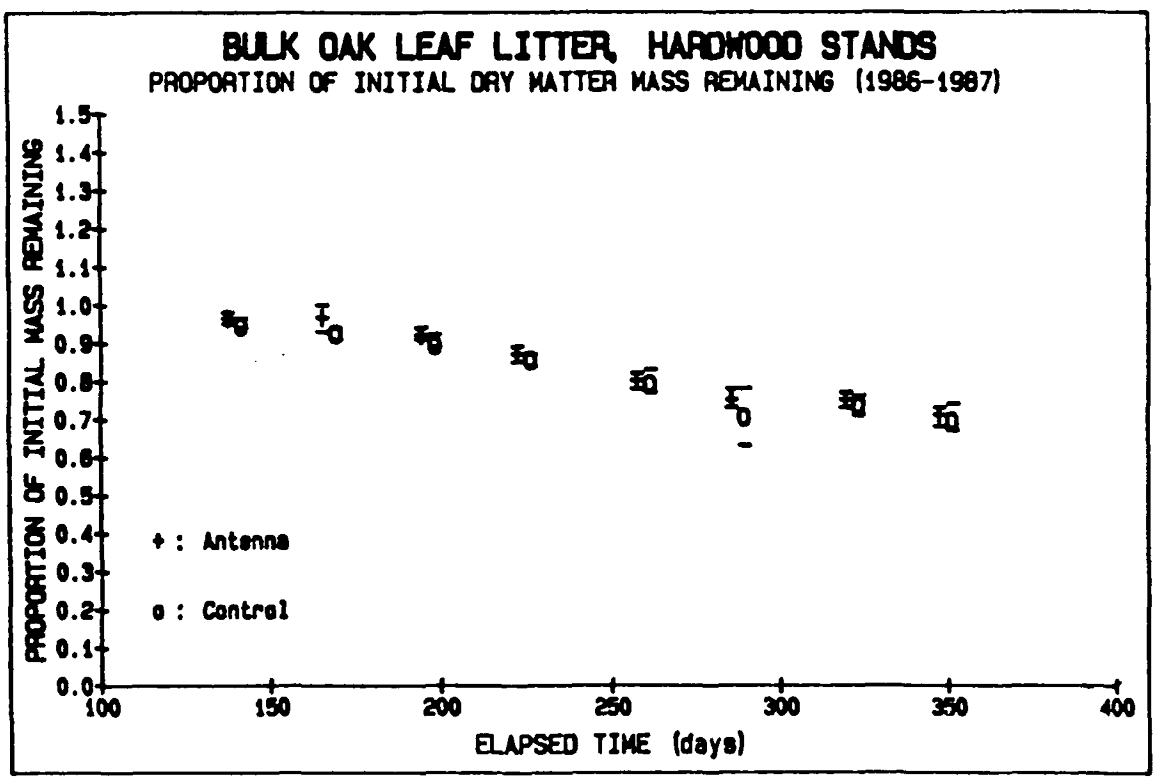
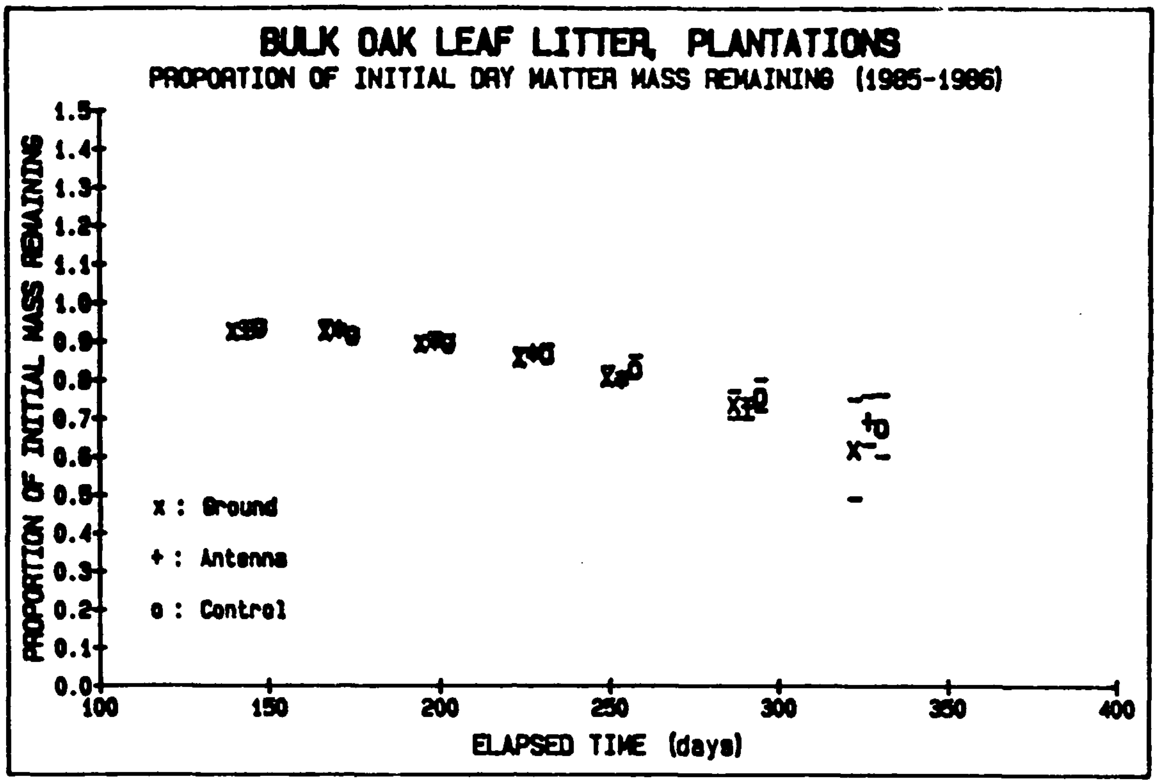
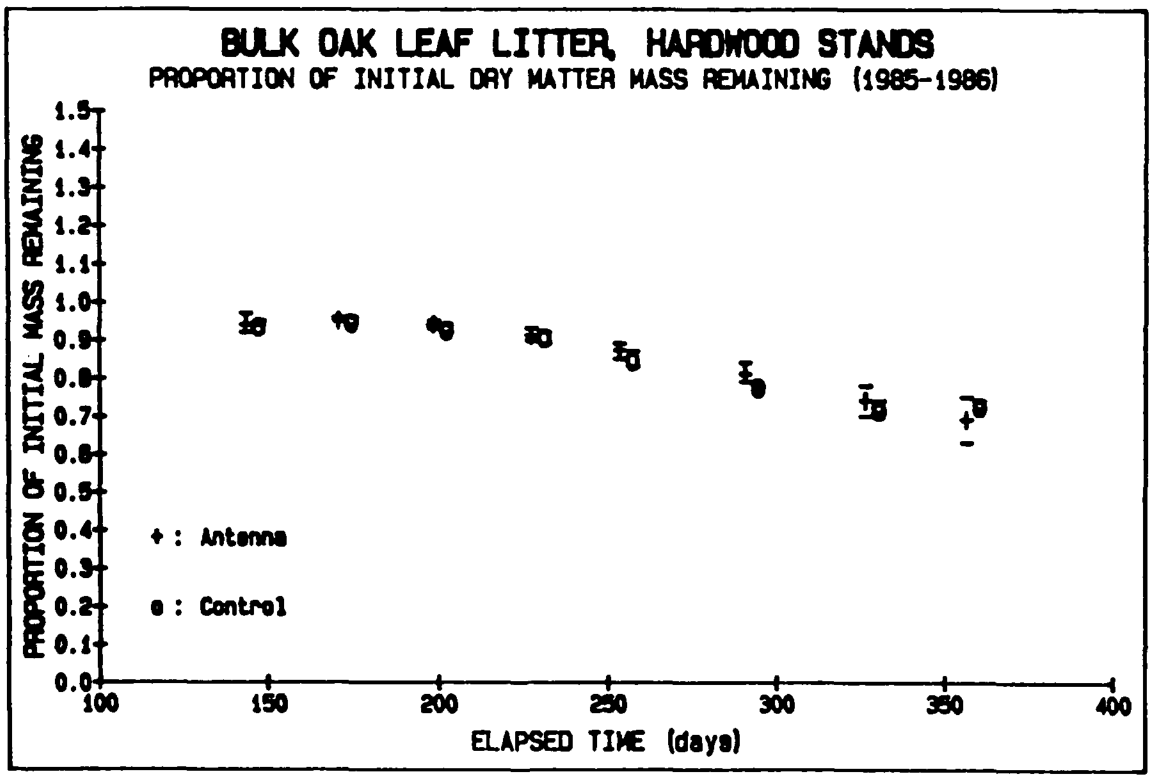

BULK OAK LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1986-1987)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 33.

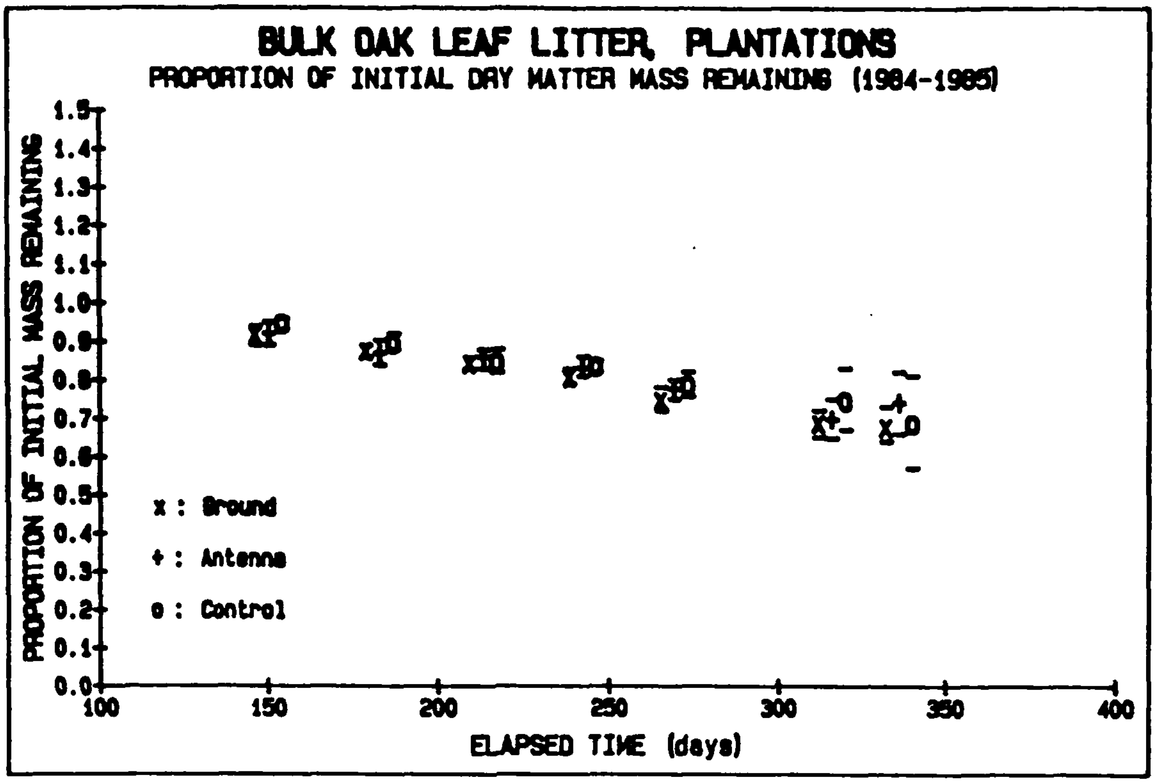


BULK OAK LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
x : Ground
+ : Antenna
o : Control
ELAPSED TIME (days)



BULK OAK LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
+ : Antenna
o : Control
ELAPSED TIME (days)

FIGURE 34.


BULK OAK LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
x : Ground
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

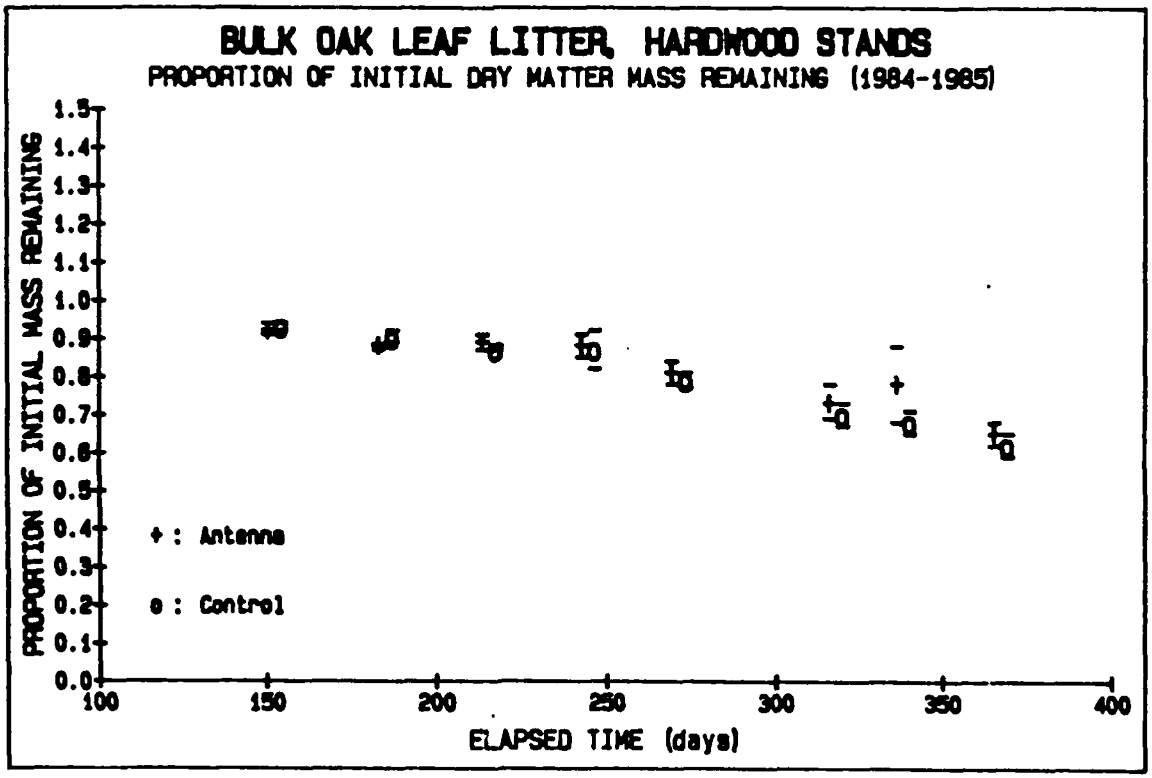

BULK OAK LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 35.

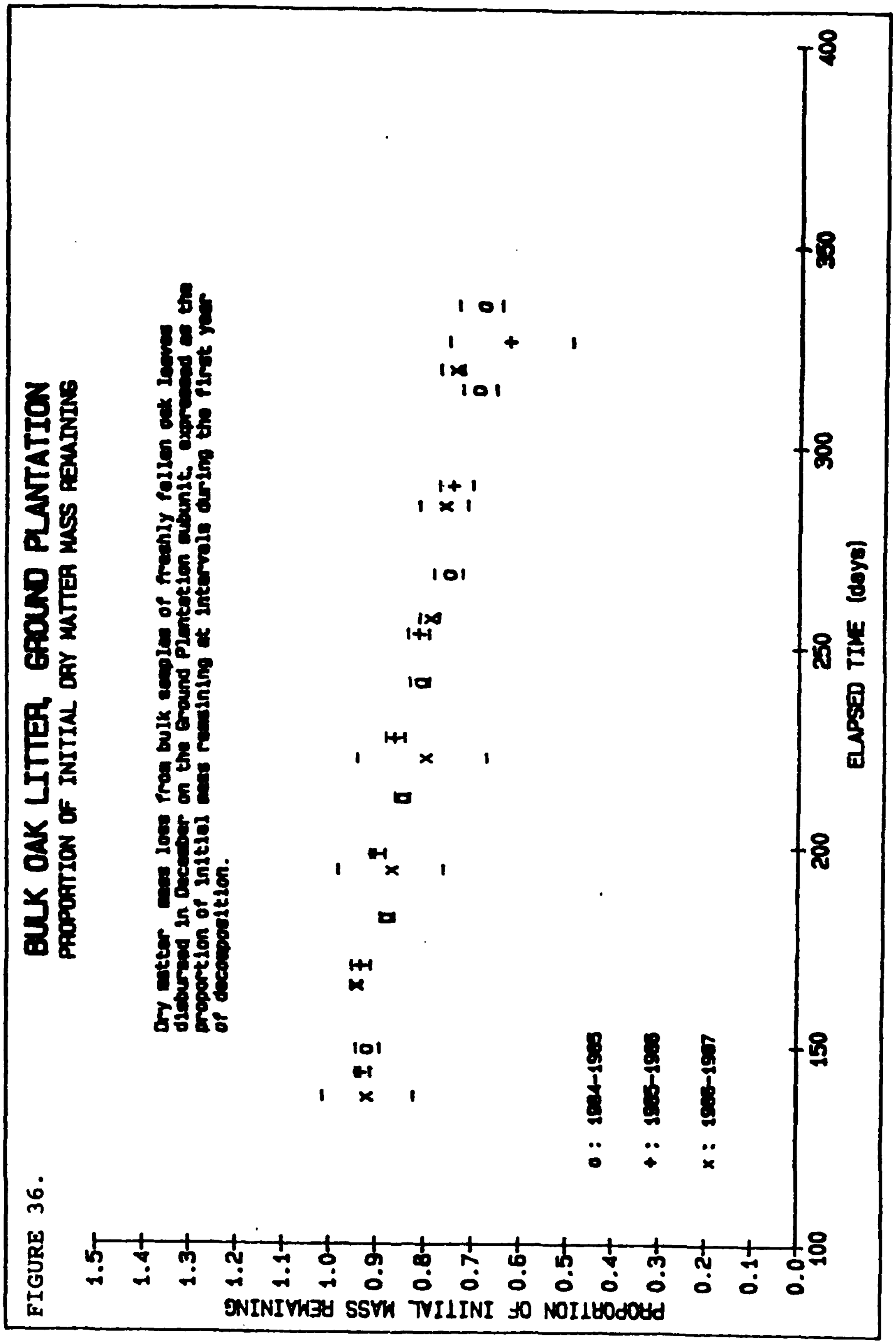

BULK OAK LITTER, GROUND PLANTATION
PROPORTION OF INITIAL DRY MATTER MASS REMAINING
Dry matter mass loss from bulk samples of freshly fallen oak leaves disbursed in December on the Ground Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
o : 1984-1985
+ : 1985-1986
x : 1986-1987
PROPORTION OF INITIAL MASS REMAINING
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 36.

FIGURE 37.

BULK OAK LITTER, ANTENNA PLANTATION
PROPORTION OF INITIAL DRY MATTER MASS REMAINING

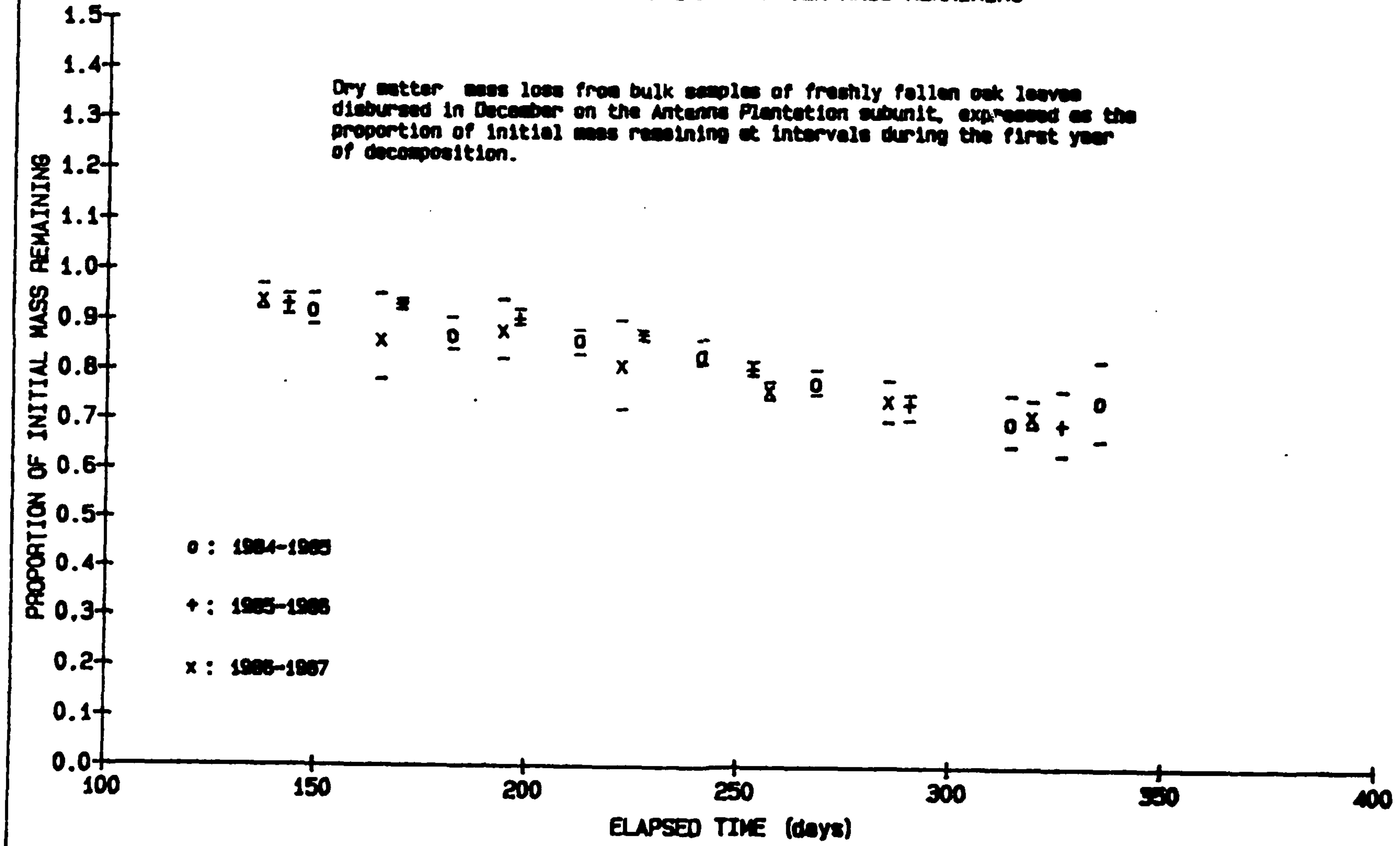


FIGURE 38.

BULK OAK LITTER, CONTROL PLANTATION

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

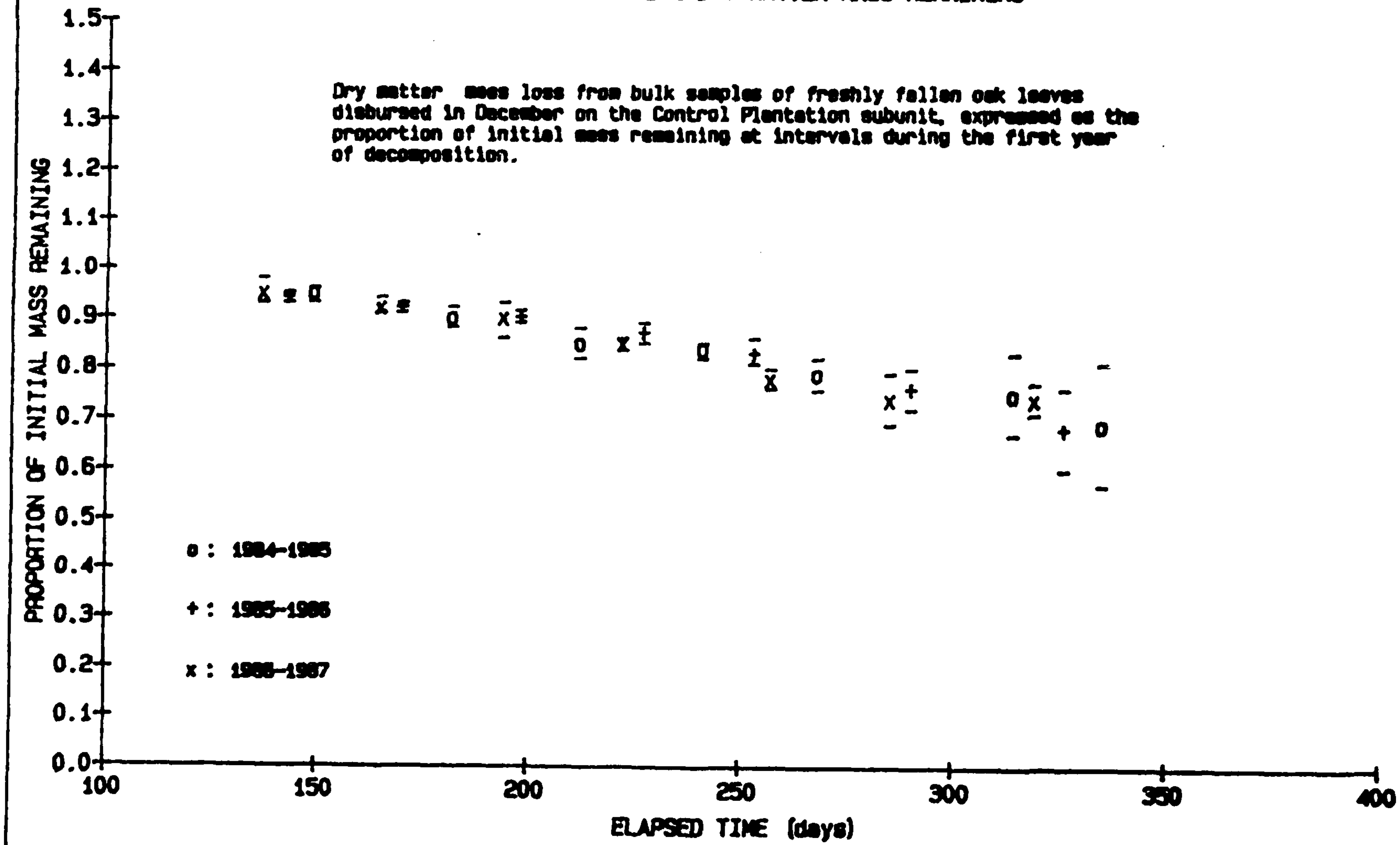


FIGURE 39.

BULK OAK LITTER, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

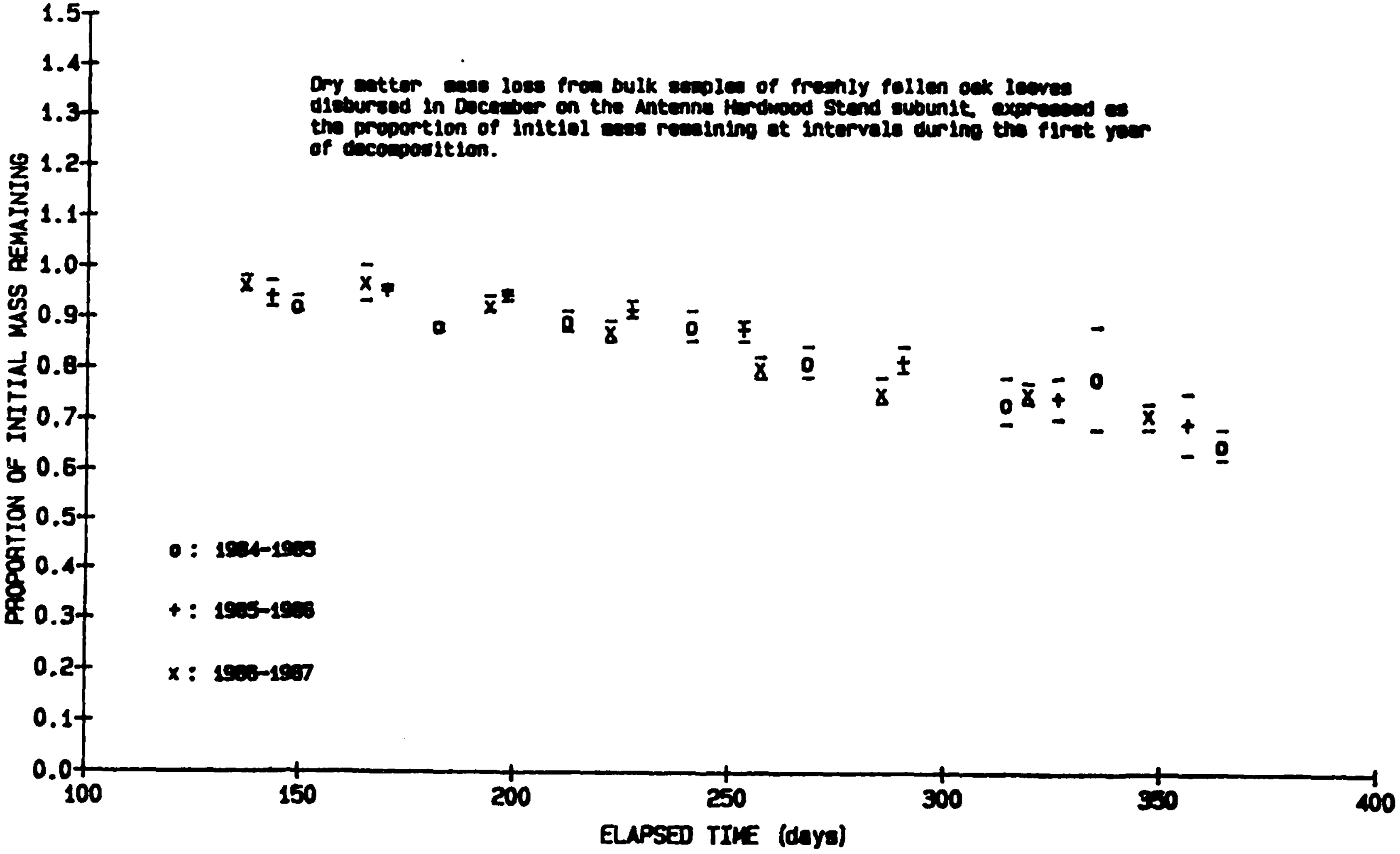
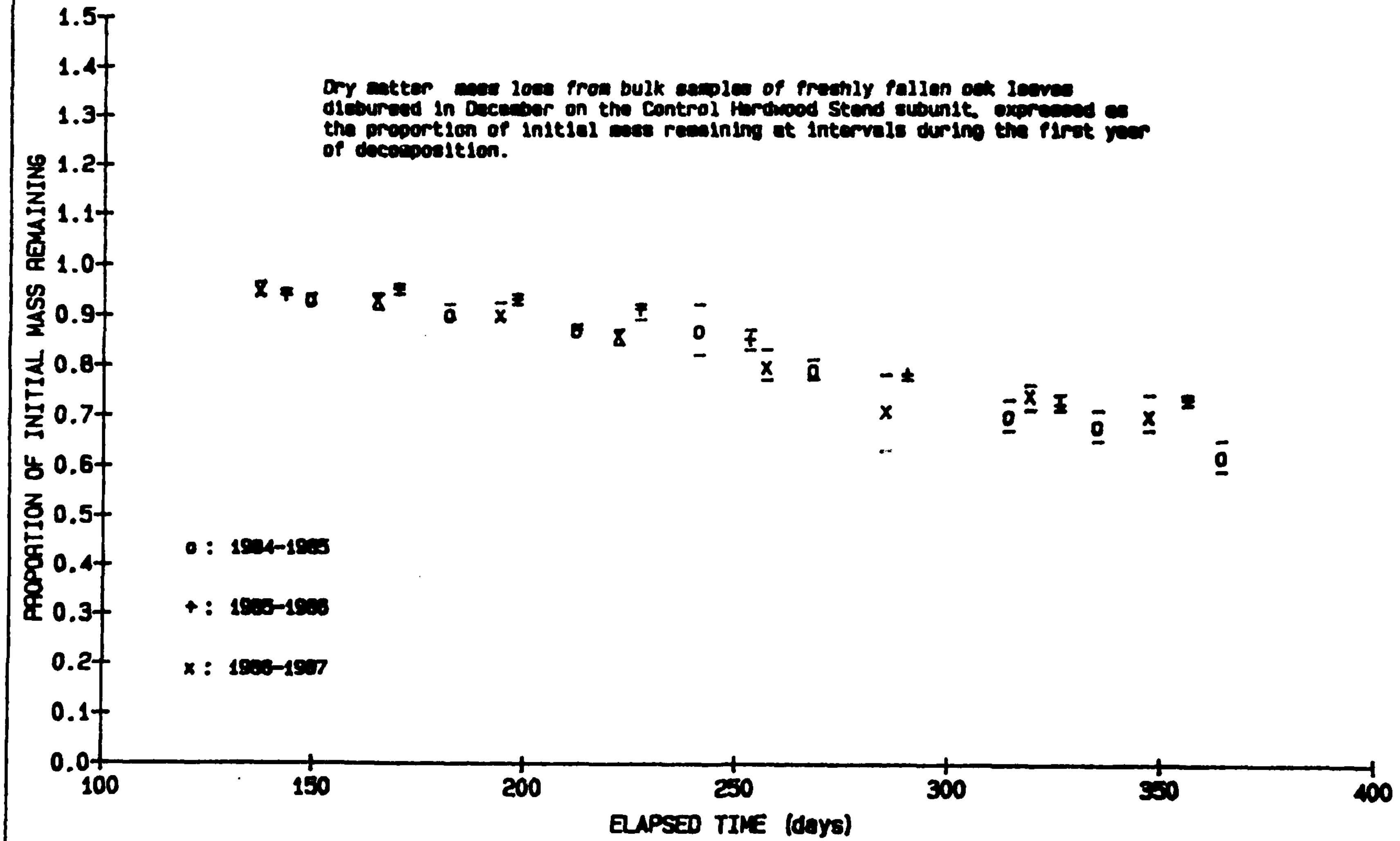


FIGURE 40.

BULK OAK LITTER, CONTROL HARDWOOD STAND

PROPORTION OF INITIAL DRY MATTER MASS REMAINING



Bulk oak leaf samples decomposed faster in the ground plantation than in the control plantation. Samples in the control hardwood stand decomposed faster than those in the antenna hardwood stand. Comparing years in plantations, 1985 samples decomposed faster than either 1986 or 1987 samples; in the hardwood stands, 1985 samples decomposed fastest and 1986 samples slowest. Significant monthly progress occurred in the plantations, while no significant progress was made in the hardwood stands during May or October. Detectable differences were extremely low, below 1 percent for yearly and subunit mean values, and below 2 percent for monthly mean values.

Figures 33a and 33b present comparisons of monthly dry matter mass loss progress during the 1986-87 study on the plantation and hardwood stand subunits, respectively. Means representing the raw data are plotted between bars depicting their associated 95 percent confidence intervals. Figures 34 and 35 present corresponding data for the 1985-86 and 1984-85 studies, respectively. As with the bulk pine samples, the similarity in bulk oak sample decomposition among plantation and hardwood stand subunits is encouraging; the significant differences detected by ANOVA would be hard to anticipate from the figures alone.

Figure 36 presents comparisons of monthly progress in dry matter mass loss during the 1984-85, 1985-86, and 1986-87 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 37 through 40 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands, respectively. Again, the significant differences detected by ANOVA would be difficult to anticipate from the figures alone.

Bulk Maple Leaf Litter

Tables 33 and 34 present the ANOVA tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 35 and 36

Table 33. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk maple leaf samples in the three plantation subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	16	6.17		84.73	0.0001	0.79
Year	2		1.83	201.59	0.0001	
Month	6		4.07	149.06	0.0001	
Plantation	2		0.15	16.76	0.0001	
Location	6		0.10	3.63	0.0017	
Error	360	1.64				
Corrected Total	376	7.80				

Table 34. ANOVA table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk maple leaf samples in the two hardwood stand subunits, by year, sampling date, and location within the subunits, and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	14	3.98		170.73	0.0001	0.90
Year	2		1.86	557.64	0.0001	
Month	7		2.12	182.08	0.0001	
Hardwood Stand	1		0.00	0.03	0.8715	
Location	4		0.01	1.94	0.1047	
Error	275	0.46				
Corrected Total	289	4.43				

Table 35. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 33.

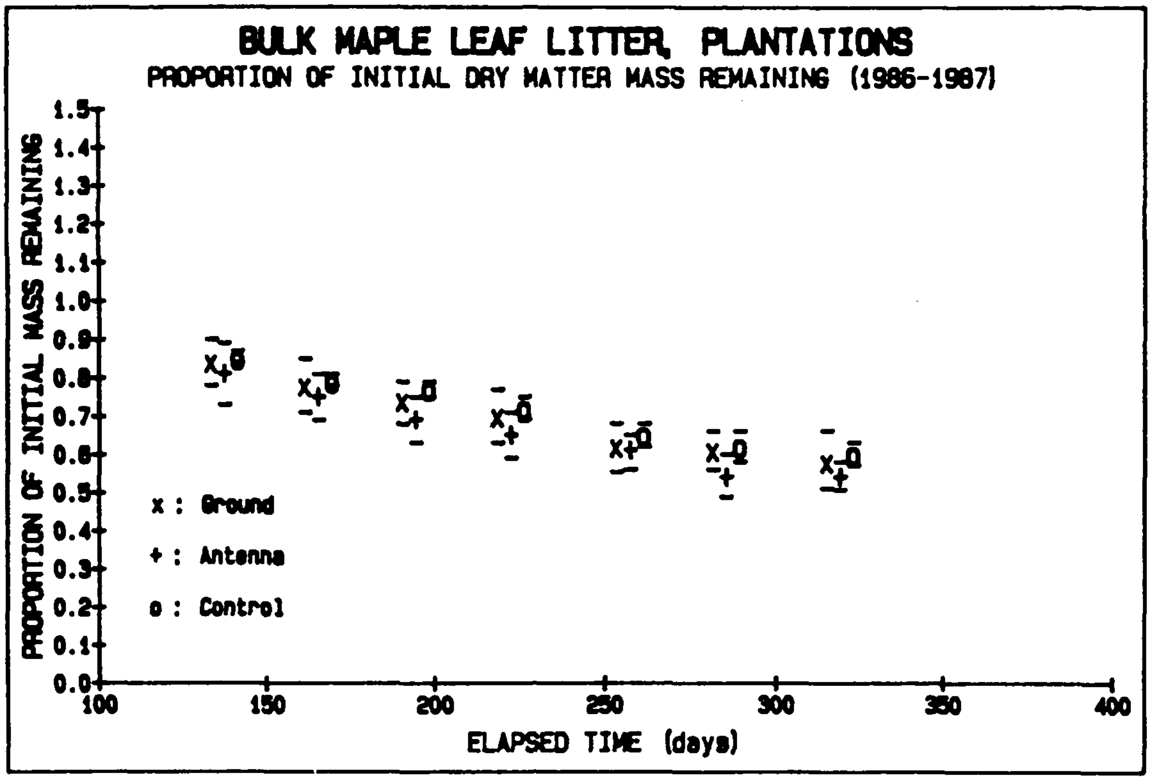
Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6				
1985	0.83	0.006	1.42	1985						
1986	0.97	0.006	1.21	1986	*					
1987	0.99	0.006	1.19	1987	*					
Month					1	2	3	4	5	6
May	1.08	0.009	1.63	May						
June	1.03	0.009	1.71	June	*					
July	0.98	0.009	1.80	July	*	*				
August	0.93	0.009	1.90	Aug	*	*	*			
September	0.87	0.009	2.03	Sept	*	*	*	*		
October	0.82	0.009	2.15	Oct	*	*	*	*	*	
November	0.78	0.009	2.26	Nov	*	*	*	*	*	*
Plantation					G	A				
Ground	0.91	0.006	1.29	Ground						
Antenna	0.92	0.006	1.28	Antenna						
Control	0.96	0.006	1.23	Control	*	*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 36. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 34.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6					
1985	0.89	0.004	0.88	1985							
1986	1.06	0.004	0.74	1986	*						
1987	1.06	0.004	0.74	1987	*						
Month					1	2	3	4	5	6	7
May	1.12	0.007	1.23	May							
June	1.08	0.007	1.27	June	*						
July	1.08	0.007	1.27	July	*						
August	1.04	0.007	1.32	Aug	*	*	*				
September	0.99	0.007	1.39	Sept	*	*	*	*			
October	0.94	0.007	1.46	Oct	*	*	*	*	*		
November	0.90	0.007	1.52	Nov	*	*	*	*	*	*	
December	0.86	0.007	1.56	Dec	*	*	*	*	*	*	
Hardwood Stand					A						
Antenna	1.00	0.003	0.59	Antenna							
Control	1.00	0.003	0.59	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.


BULK MAPLE LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1986-1987)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
x : Ground
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

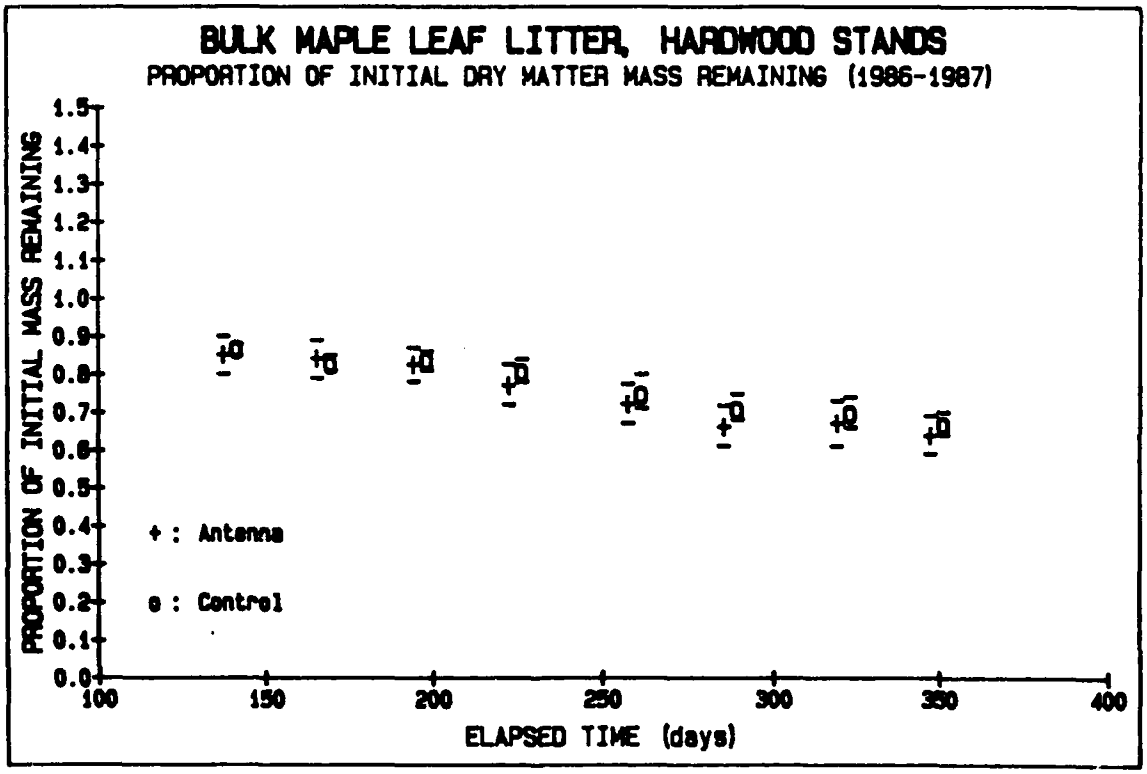
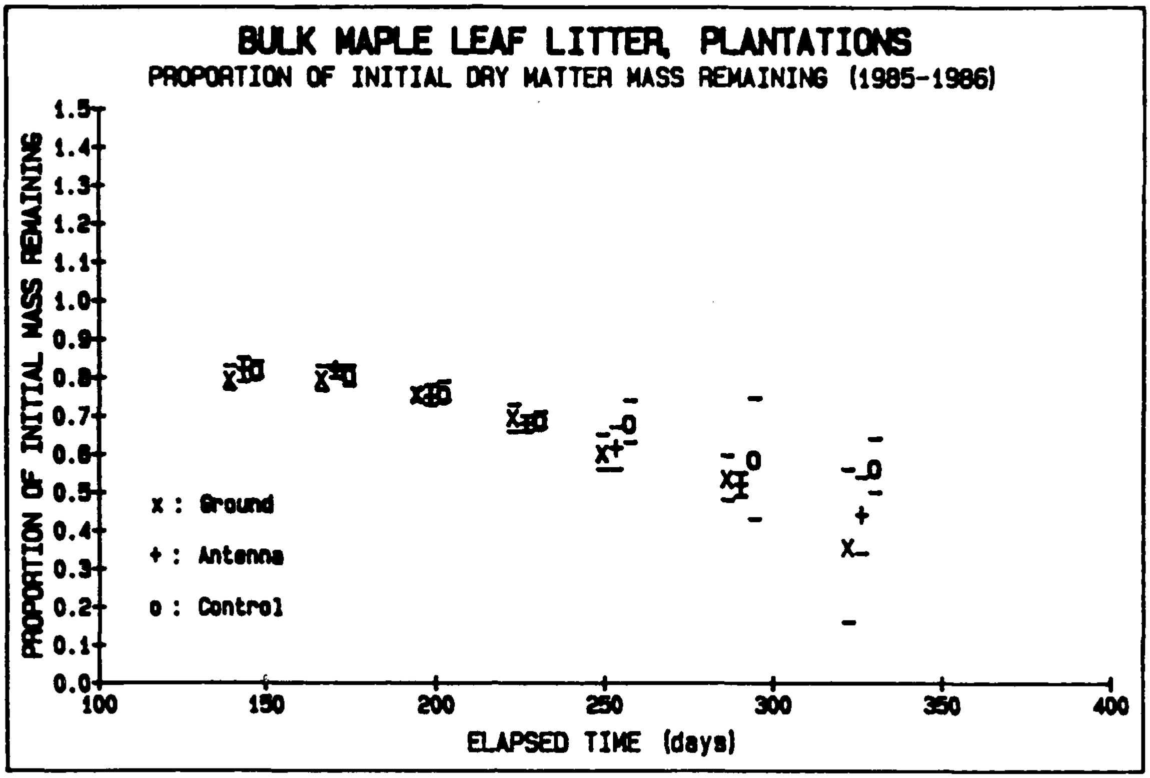

BULK MAPLE LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1986-1987)
PROPORTION OF INITIAL MASS REMAINING
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 41.


BULK MAPLE LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
x : Ground
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

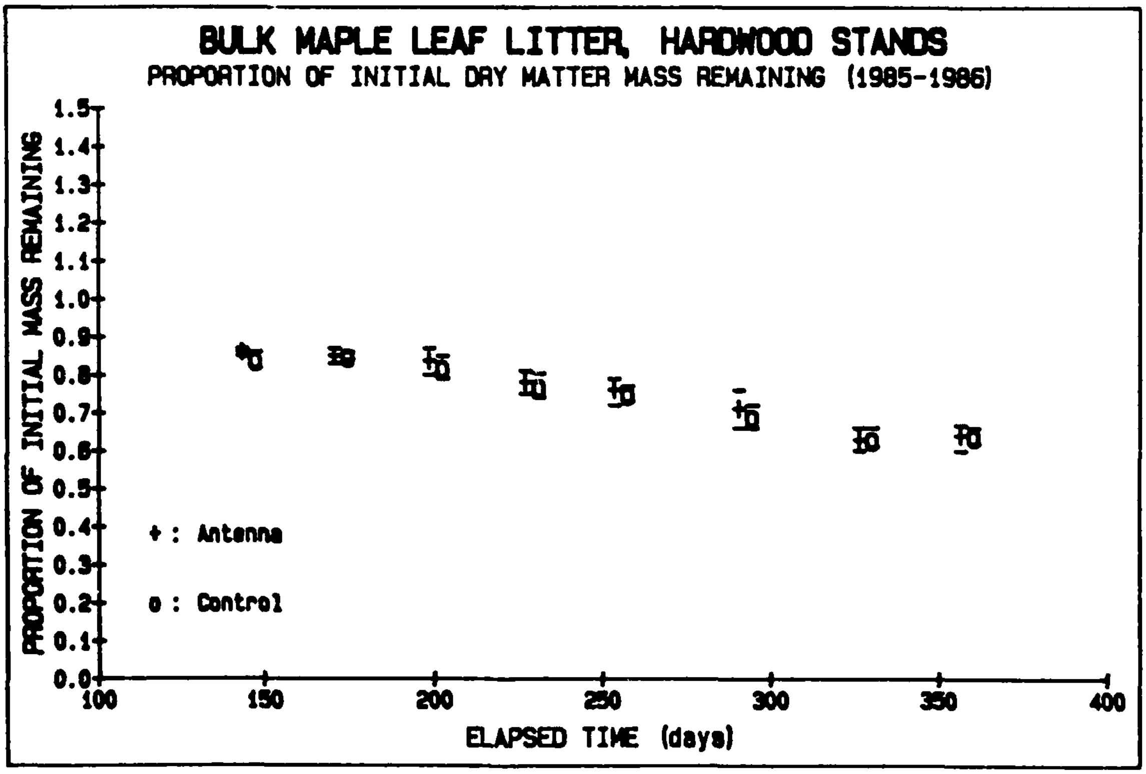
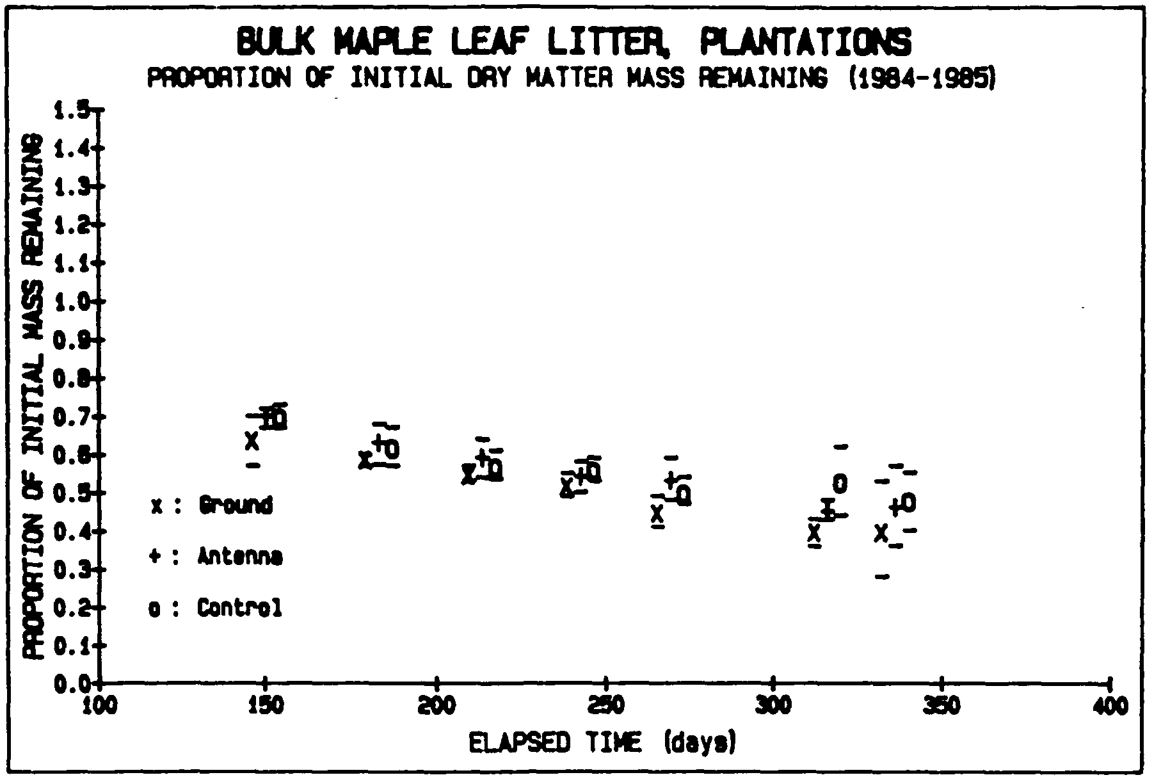

BULK MAPLE LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 42.


BULK MAPLE LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
x : Ground
+ : Antenna
o : Control
ELAPSED TIME (days)

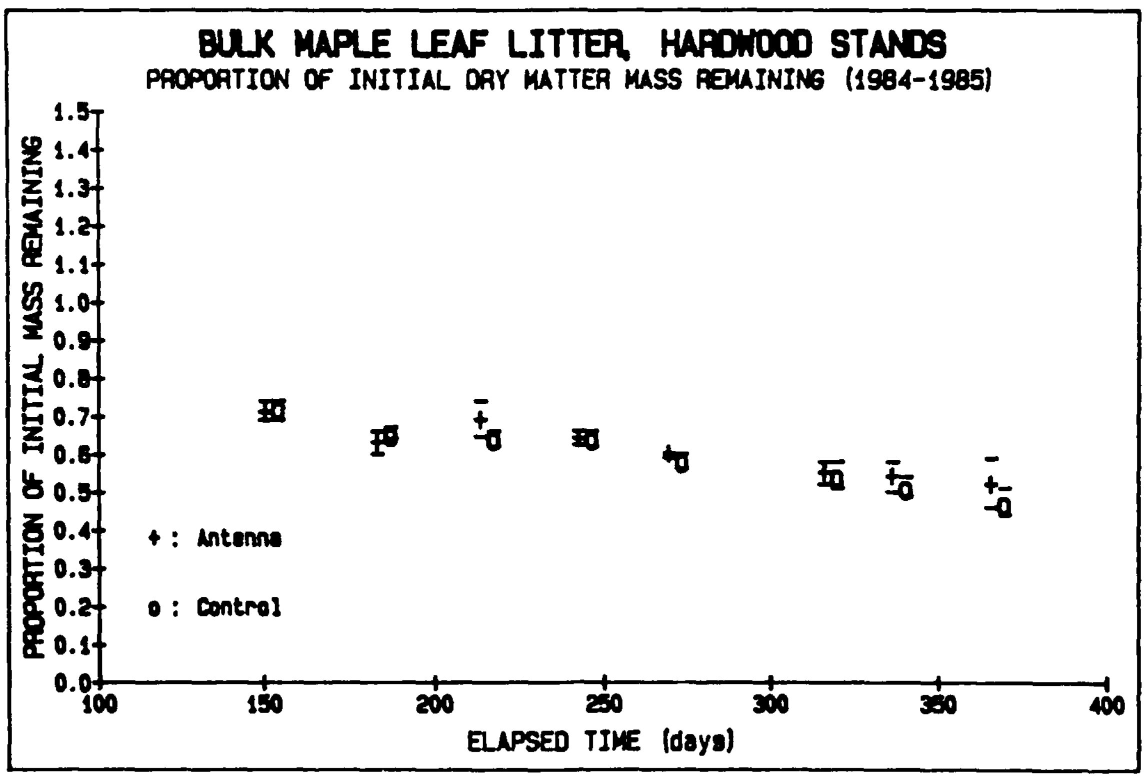
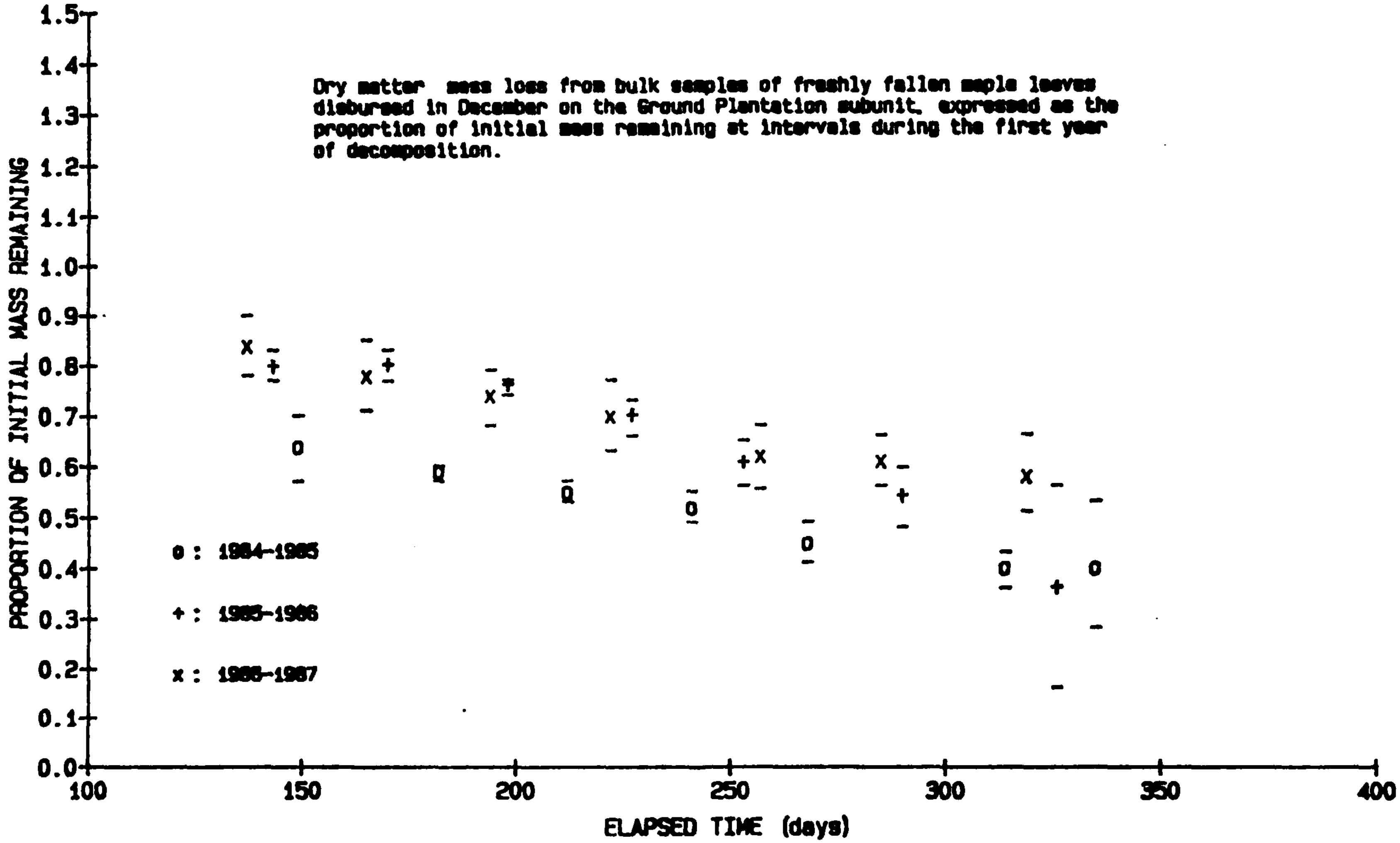

BULK MAPLE LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL DRY MATTER MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
+ : Antenna
o : Control
ELAPSED TIME (days)

FIGURE 43.

FIGURE 44.

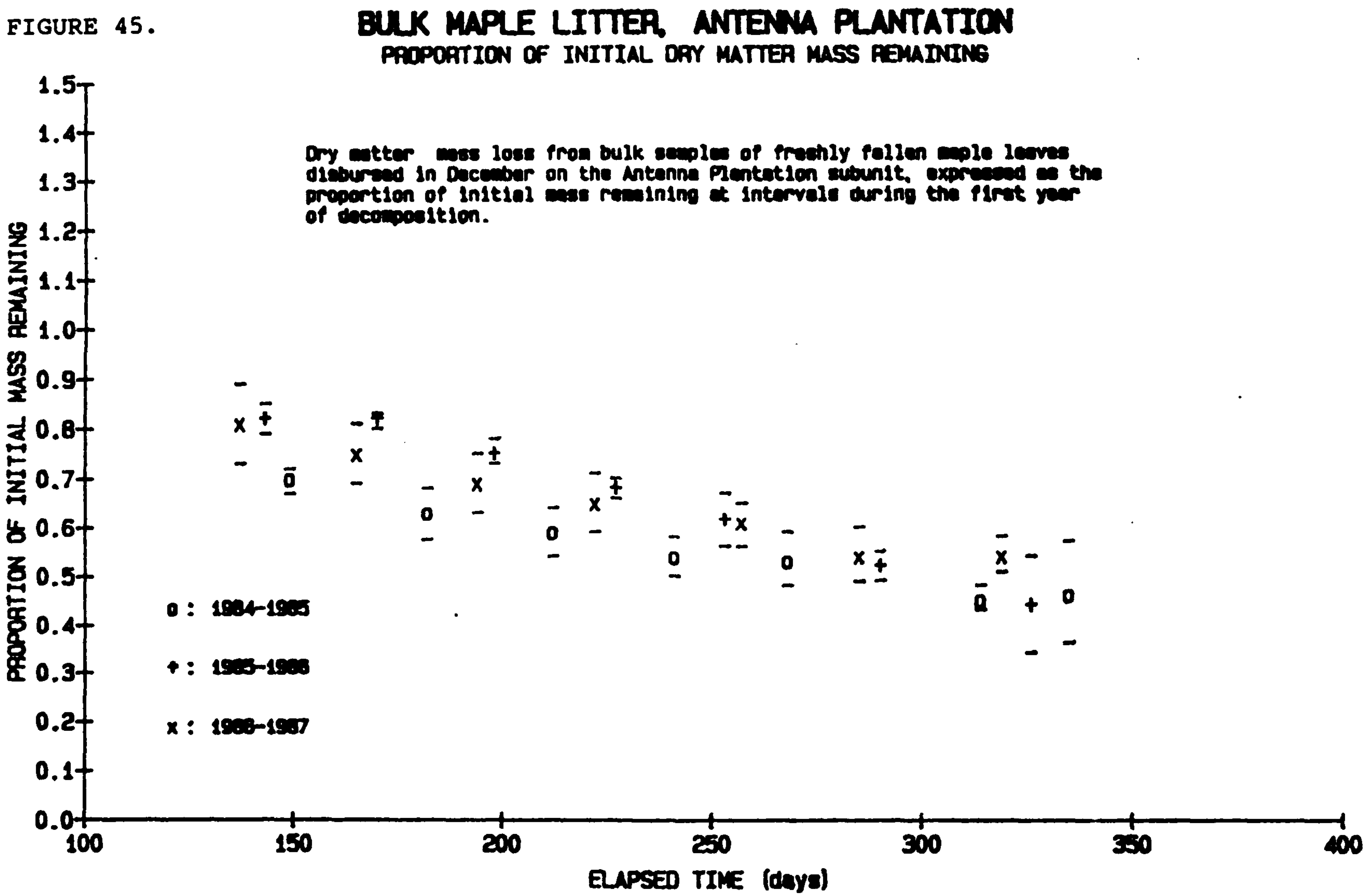
BULK MAPLE LITTER, GROUND PLANTATION

PROPORTION OF INITIAL DRY MATTER MASS REMAINING



Dry matter mass loss from bulk samples of freshly fallen maple leaves disbursed in December on the Ground Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

FIGURE 45.



BULK MAPLE LITTER, ANTENNA PLANTATION
PROPORTION OF INITIAL DRY MATTER MASS REMAINING
Dry matter mass loss from bulk samples of freshly fallen maple leaves disbursed in December on the Antenna Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
o : 1984-1985
+ : 1985-1986
x : 1986-1987
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
100
150
200
250
300
350
400

FIGURE 46.

BULK MAPLE LITTER, CONTROL PLANTATION

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

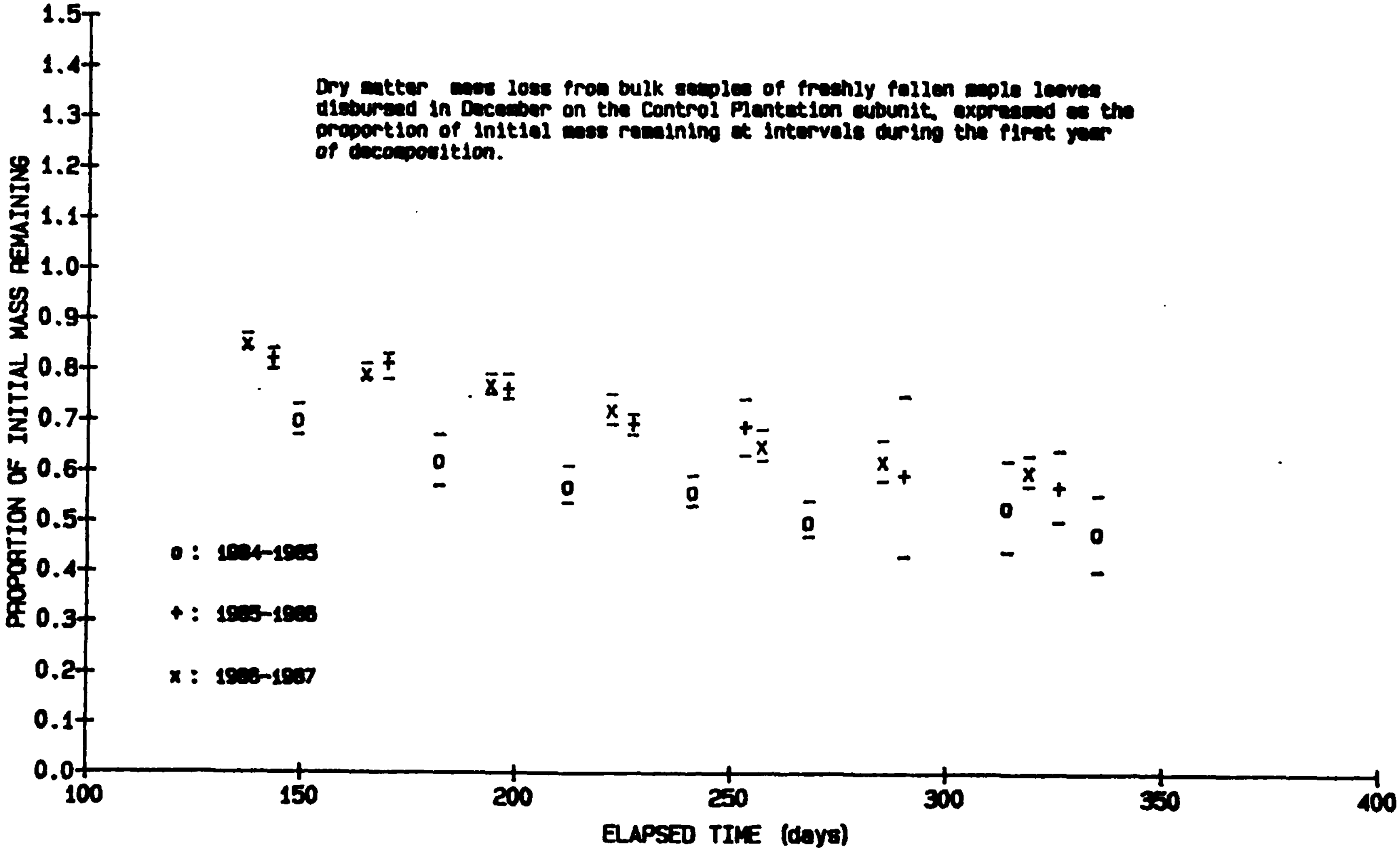


FIGURE 47.

BULK MAPLE LITTER, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL DRY MATTER MASS REMAINING

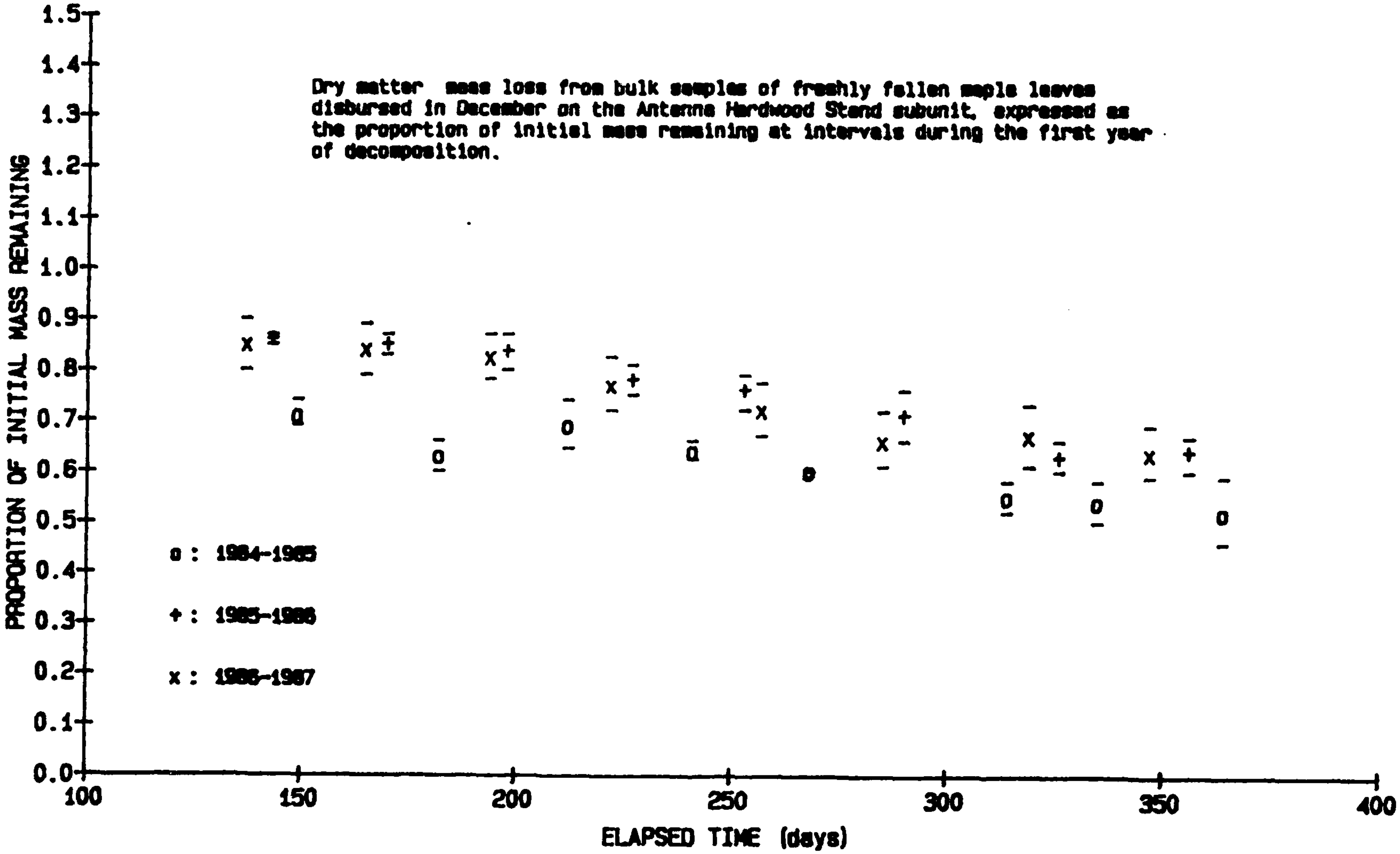
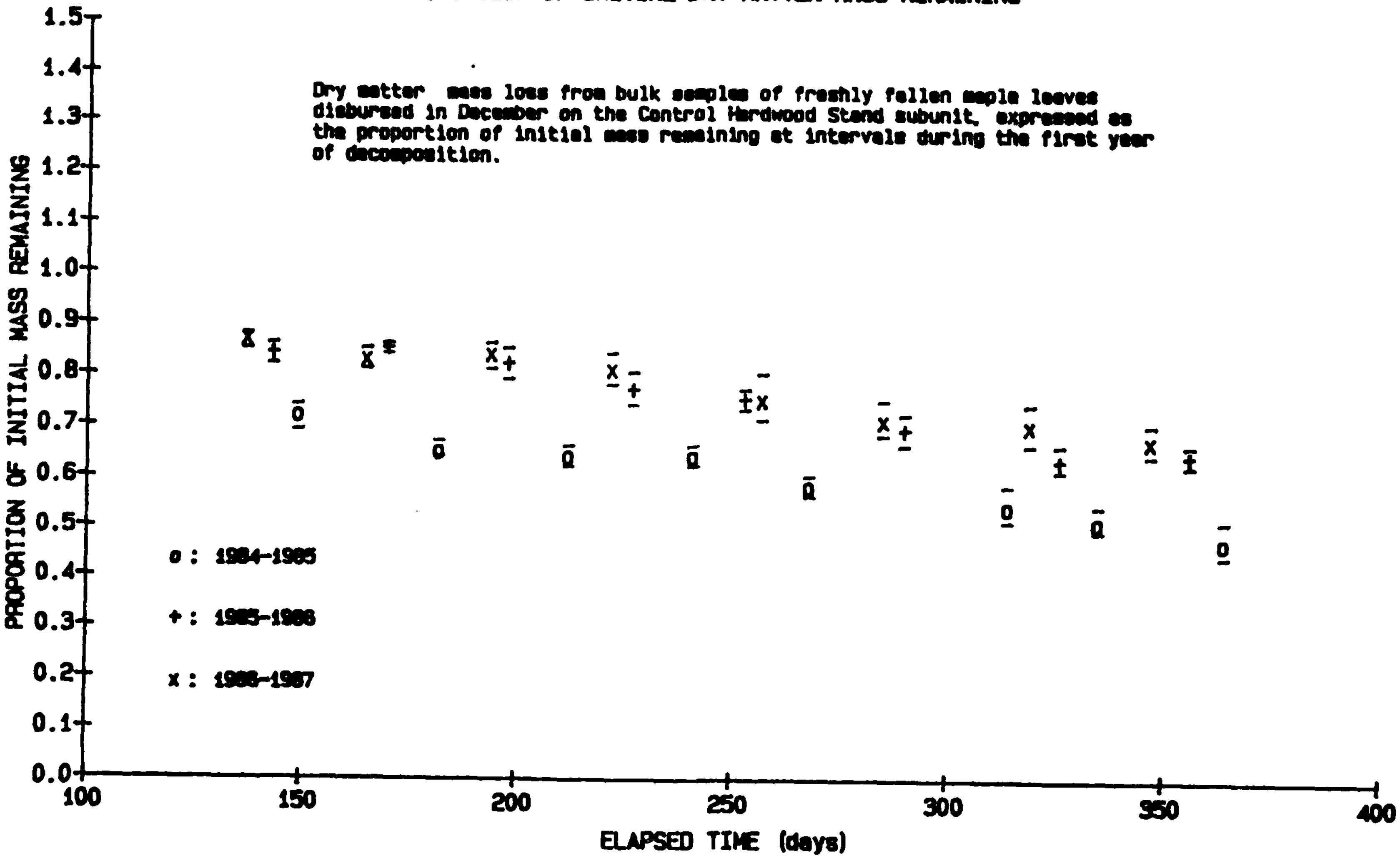


FIGURE 48. **BULK MAPLE LITTER, CONTROL HARDWOOD STAND**

PROPORTION OF INITIAL DRY MATTER MASS REMAINING



present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANOVAs.

Bulk maple leaves decomposed faster in the ground and antenna plantations than in the control plantation. No difference was detected between the antenna and control hardwood stands. Comparing years in the plantation and hardwood stand subunits alike, 1985 samples decomposed faster than did 1986 or 1987 samples. Significant monthly progress occurred in the plantation subunits. Significant monthly progress did not occur in the hardwood stands during June or November. Detectable differences were very low, below 2.5 percent for yearly, monthly and subunit mean values.

Figures 41a and 41b present comparisons of monthly progress in dry matter mass loss during the 1986-87 study on the plantation and hardwood stand subunits, respectively. Means representing the raw (untransformed) data are plotted between bars depicting their associated 95 percent confidence intervals. Figures 42 and 43 present corresponding data for the 1985-86 and 1984-85 studies. The bulk maple data tend to be slightly more variable than the bulk pine and bulk oak data. However, they also tend to be somewhat less variable than the individual maple leaf data. The similarity in bulk maple leaf decomposition among hardwood stand subunits is especially encouraging. ANOVA detected no significant difference between hardwood stand subunits.

Figure 44 presents monthly progress in dry matter mass loss during the 1984-85, 1985-86, and 1986-87 studies on the ground unit plantation. Again, means are plotted between bars depicting their associated 95 percent confidence intervals. Figures 45 through 48 present corresponding comparisons for the antenna and control unit plantations and for the antenna and control unit hardwood stands, respectively. Again, the greater variability in bulk maple sample decomposition than that observed for pine or oak is clearly depicted in these figures. The significantly faster decomposition during 1985 than during 1986 or 1987 in both the plantation and hardwood stand subunits is readily apparent.

ANOVA Results - Summary

The following outline summarizes the results of ANOVA on transformed dry matter mass loss data.

I. Subunits
   A. Plantations
      1. Pine
         a. Individual fascicles decomposed faster in the control plantation than in the antenna plantation.
         b. Bulk samples also decomposed faster in the control plantation than in the antenna plantation.
      2. Oak
         a. Individual leaves decomposed fastest in the antenna plantation.
         b. Bulk samples decomposed faster in the ground plantation than in the control plantation.
      3. Maple
         a. Individual leaves decomposed fastest in the ground plantation and slowest in the control plantation.
         b. Bulk samples decomposed faster in the ground and antenna plantations than in the control plantation.
   B. Hardwood Stands
      1. Pine
         a. No differences were found using individual fascicles.
         b. No differences were found using bulk samples.
      2. Oak
         a. No differences were found using individual leaves.
         b. Bulk samples decomposed faster in the control hardwood stand.
      3. Maple
         a. Individual leaves decomposed faster in the control hardwood stand.
         b. No difference was found using bulk samples.
II. Years
   A. Plantations
      1. Pine
         a. 1987 fascicles decomposed fastest and 1985 fascicles slowest.
         b. 1985 bulk samples decomposed fastest and 1987 samples slowest.
      2. Oak
         a. 1987 leaves decomposed fastest and 1986 leaves slowest.
         b. 1985 bulk samples decomposed faster than either 1986 or 1987 samples.
      3. Maple
         a. No difference was detected between 1984 and 1985 using individual leaves.
         b. 1985 bulk samples decomposed faster than either 1986 1987 samples.

B. Hardwood Stands
   1. Pine
      a. 1985 fascicles decomposed fastest and 1986 fascicles slowest.
      b. 1985 bulk samples decomposed faster than either 1986 or 1987 samples.
   2. Oak
      a. 1985 and 1987 leaves decomposed faster than 1986 leaves.
      b. 1985 bulk samples decomposed fastest and 1986 samples slowest.
   3. Maple
      a. 1985 leaves decomposed faster than 1986 leaves.
      b. 1985 bulk samples decomposed faster than either 1986 or 1987 samples.

From the above, it appears that pine decomposition among the 3 plantations proceeds fastest under conditions prevailing at the control plantation, while oak and maple decomposition tend to be favored by conditions prevailing at the antenna and/or ground plantation(s). No difference in pine decomposition was detected between hardwood stands, but oak and maple showed some tendency to decompose faster in the control hardwood stand.

For some yet unexplained reason(s), individual fascicle/leaf samples of pine and oak in the plantation subunits decomposed fastest in 1987, while bulk samples of all 3 species decomposed fastest in 1985. Both individual and bulk samples of all 3 species in the hardwood stand subunits tended to decompose fastest in 1985 as well, though individual oak leaves did not decompose significantly faster in 1985 than in 1987.

Covariate Selection for Preliminary ANACOV

The relationships between transformed dry matter mass loss and leaf density (mass per unit surface area) were investigated for individual oak and maple leaves, in order to determine whether any of the observed variability in mass loss might be explained by differences in decay rate between "shade" leaves (generally larger and thinner) and "sun" leaves (generally smaller and thicker). The variability in decomposition rate observed for individual maple leaves (Tables 17 - 20 and Figures

17 - 23), especially on the plantation subunits, is great enough to prevent detection of modest shifts in decomposition rate due to limited environmental perturbation. In an effort to increase the uniformity of conditions for sample leaf decomposition, and thus to reduce unexplained variability, all possibility for sample maple leaves to overlap and thereby shelter portions of other sample leaves from weathering was eliminated in the 1985-86 study by confining each sample maple leaf to one-quarter of a litter envelope. This also eliminated the problem of broken petioles associated with application of the tethered leaf method to maple and helped to maintain leaf integrity. In our 1986 Annual Report, we presented Pearson's product moment correlation coefficients between individual leaf mass loss (as of the early November sampling date) and both leaf surface area and density, for oak and maple, as Tables 67 and 68, respectively. No useful relationship was detected. Nevertheless, a broader analysis, covering all months of the 1984-85, 1985-86, and 1986-87 studies, has been conducted. The results of these analyses are presented as Tables 37 and 38, for oak and maple, respectively. Our original choice of November as the focal month for preliminary analysis, especially for the 1985-86 study, was unfortunate. The broader analysis indicates the existence of a generally significant relationship between dry matter mass loss and initial leaf density, especially for oak. The relationship for oak seems to hold up quite well throughout the year, while the relationship for maple appears to deteriorate somewhat as the year progresses, especially in the plantation subunits. As a result of these analyses, initial leaf density was included as a potential covariate in our attempts to use ANACOV to explain differences in dry matter mass loss detected by 3-way ANOVA among years, sampling dates, dates, and plantation or hardwood stand subunits.

The relationships between three selected temperature- and moisture-related weather variables and transformed dry matter mass loss are presented as correlation analyses for pine, oak and maple in Tables 39 through 41, respectively. In each table,

Table 37. Relationships between individual oak leaf decomposition (proportion of initial dry matter mass remaining, transformed to arcsin square root) and initial leaf density (gm/cm³), expressed as Pearson's product moment correlation coefficients.

Year	Month[a]	Plantations[b]			Hardwood Stands[c]		
		r[d]	P[e]	n[f]	r	P	n
1985	May	0.19	0.0899	79	0.45	0.0007	54
	Jun	0.40	0.0003	81	0.51	0.0001	54
	Jul	0.33	0.0024	81	0.29	0.0365	53
	Aug	0.44	0.0001	90	0.31	0.0144	60
	Sep	0.42	0.0001	90	0.65	0.0001	60
	Oct	0.26	0.0141	90	0.22	0.0899	59
	Nov	0.25	0.0184	90	0.36	0.0048	60
	Dec				0.35	0.0066	60
1986	May	0.33	0.0015	90	0.25	0.0568	60
	Jun	0.25	0.0181	90	0.20	0.1339	60
	Jul	0.21	0.0487	90	0.20	0.1290	60
	Aug	0.33	0.0017	90	0.53	0.0001	60
	Sep	0.30	0.0041	90	0.23	0.0775	60
	Oct	0.25	0.0158	90	0.32	0.0122	60
	Nov	0.05	0.6357	90	0.18	0.1709	60
	Dec				0.23	0.0738	60
1987	May	0.48	0.0001	72	0.29	0.0467	48
	Jun	0.51	0.0001	72	0.33	0.0230	48
	Jul	0.70	0.0001	70	0.56	0.0001	48
	Aug	0.68	0.0001	69	0.66	0.0001	48
	Sep	0.68	0.0001	70	0.47	0.0007	48
	Oct	0.52	0.0001	70	0.72	0.0001	48
	Nov	0.41	0.0001	84	0.48	0.0007	47
	Dec				0.64	0.0001	48

a/ month of sample retrieval from the field
b/ Data from the Ground, Antenna, and Control plantation subunits were included.
c/ Data from both the Antenna and Control hardwood stand subunits were included.
d/ Pearson product moment correlation coefficients
e/ the attained level of significance, p, for the correlation
f/ number of observations

Table 38. Relationships between individual maple leaf decomposition (proportion of initial dry matter mass remaining, transformed to arcsin square root) and initial leaf density (gm/cm^2), expressed as Pearson's product moment correlation coefficients.

Year	Month[a]	Plantations[b]			Hardwood Stands[c]		
		r[d]	P[e]	n[f]	r	P	n
1985	May	0.25	0.0207	88	0.46	0.0005	55
	Jun	-0.34	0.0013	89	0.52	0.0001	60
	Jul	0.30	0.0040	90	0.42	0.0008	60
	Aug	0.31	0.0035	89	0.63	0.0001	60
	Sep	0.02	0.8507	90	0.66	0.0001	60
	Oct	0.01	0.9608	88	0.29	0.0278	58
	Nov	0.01	0.9559	89	0.15	0.2643	60
	Dec				0.18	0.1783	60
1986	May	0.53	0.0009	36	0.66	0.0005	24
	Jun	0.43	0.0093	36	0.55	0.0056	24
	Jul	0.45	0.0055	36	0.22	0.2961	24
	Aug	0.69	0.0001	36	0.48	0.0172	24
	Sep	0.38	0.0491	36	0.50	0.0119	24
	Oct	0.32	0.1224	24	0.56	0.0044	24
	Nov	0.22	0.4035	17	0.01	0.9461	24
	Dec				0.51	0.0219	20

a/ month of sample retrieval from the field
b/ Data from the Ground, Antenna, and Control plantation subunits were included.
c/ Data from both the Antenna and Control hardwood stand subunits were included.
d/ Pearson product moment correlation coefficients
e/ the attained level of significance, p, for the correlation
f/ number of observations

Table 39. Relationships between bulk and individual pine needle decomposition (proportion of initial dry matter mass remaining, transformed to arcsin square root) and selected environmental parameters of air and soil temperature and precipitation, expressed as Pearson's product moment correlation coefficients.

Variable	Correlation Coefficient (r)					
	Plantations[a]			Hardwood Stands[b]		
	1985	1986	1987	1985	1986	1987
	-- Bulk Samples --					
ATDDRT[c]	-0.92	-0.89	-0.96	-0.92	-0.97	-0.98
	0.0001[f]	0.0001	0.0001	0.0001	0.0001	0.0001
	126[g]	127	126	94	84	84
ST5DDRT[d]	-0.92	-0.89	-0.95	-0.92	-0.97	-0.98
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	126	127	126	94	84	84
PR.01RT[e]	-0.93	-0.91	-0.94	-0.93	-0.98	-0.97
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	126	127	126	94	84	84
	-- Individual Leaves --					
ATDDRT	-0.88	-0.88	-0.89	-0.89	-0.87	-0.93
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	520	546	429	465	406	308
ST5DDRT	-0.88	-0.88	-0.89	-0.88	-0.88	-0.93
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	520	546	429	465	406	308
PR.01RT	-0.89	-0.90	-0.89	-0.88	-0.90	-0.92
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	520	546	429	465	406	308

a/ Data from the Ground, Antenna and Control plantation subunits were included.
b/ Data from both the Antenna and Control hardwood stand subunits were included.
c/ running total of air temperature degree days (4.4 °C basis), based on mean daily temperature
d/ running total of soil temperature degree days (4.4°C basis, 5cm below ground level), based on mean daily temperature
e/ number of days with at least .01 in. precipitation
f/ the attained level of significance, p, for the correlation
g/ number of observations

Table 40. Relationships between bulk and individual oak leaf decomposition (proportion of initial dry matter mass remaining, transformed to arcsin square root) and selected environmental parameters of air and soil temperature and precipitation, expressed as Pearson's product moment correlation coefficients.

Variable	Correlation Coefficient (r)					
	Plantations[a]			Hardwood Stands[b]		
	1985	1986	1987	1985	1986	1987
	-- Bulk Samples --					
ATDDRT[c]	-0.88	-0.87	-0.83	-0.88	-0.90	-0.94
	0.0001[f]	0.0001	0.0001	0.0001	0.0001	0.0001
	126[g]	127	128	96	84	84
ST5DDRT[d]	-0.89	-0.88	-0.84	-0.89	-0.92	-0.95
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	126	127	128	96	84	84
PR.01RT[e]	-0.88	-0.93	-0.82	-0.91	-0.95	-0.93
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	126	127	128	96	84	84
	-- Individual Leaves --					
ATDDRT	-0.74	-0.77	-0.83	-0.79	-0.81	-0.87
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	601	630	507	461	420	335
ST5DDRT	-0.75	-0.77	-0.83	-0.80	-0.82	-0.87
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	601	630	507	461	420	335
PR.01RT	-0.76	-0.77	-0.82	-0.83	-0.85	-0.86
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	601	630	507	461	420	335

a/ Data from the Ground, Antenna, and Control plantation subunits were included.
b/ Data from both the Antenna and Control hardwood stand subunits were included.
c/ running total of air temperature degree days (4.4 °C basis), based on mean daily temperature
d/ running total of soil temperature degree days (4.4°C basis, 5cm below ground level), based on mean daily temperature
e/ number of days with at least .01 in. precipitation
f/ the attained level of significance, p, for the correlation
g/ number of observations

Table 41. Relationships between bulk and individual maple leaf decomposition (proportion of initial dry matter mass remaining, transformed to arcsin square root) and selected environmental parameters of air and soil temperature and precipitation, expressed as Pearson's product moment correlation coefficients.

Variable	Correlation Coefficient (r)					
	Plantations[a]			Hardwood Stands[b]		
	1985	1986	1987	1985	1986	1987
-- Bulk Samples --						
ATDDRT[c]	-0.77	-0.83	-0.84	-0.87	-0.89	-0.83
	0.0001[f]	0.0001	0.0001	0.0001	0.0001	0.0001
	126[g]	125	126	95	84	84
ST5DDRT[d]	-0.78	-0.84	-0.86	-0.87	-0.90	-0.85
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	126	125	126	95	84	84
PR.01RT[e]	-0.77	-0.89	-0.84	-0.89	-0.92	-0.85
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	126	125	126	95	84	84
-- Individual Leaves --						
ATDDRT	-0.55	-0.79		-0.56	-0.68	
	0.0001	0.0001		0.0001	0.0001	
	627	213		474	168	
ST5DDRT	-0.57	-0.80		-0.56	-0.69	
	0.0001	0.0001		0.0001	0.0001	
	627	213		474	168	
PR.01RT	-0.57	-0.76		-0.54	-0.73	
	0.0001	0.0001		0.0001	0.0001	
	627	213		474	168	

a/ Data from the Ground, Antenna, and Control plantation subunits were included.
b/ Data from both the Antenna and Control hardwood stand subunits were included.
c/ running total of air temperature degree days (4.4 °C basis), based on mean daily temperature
d/ running total of soil temperature degree days (4.4°C basis, 5cm below ground level), based on mean daily temperature
e/ number of days with at least .01 in. precipitation
f/ the attained level of significance, p, for the correlation
g/ number of observations

Pearson product moment correlation coefficients are presented for bulk and individual leaf samples representing the plantation and hardwood stand subunits during each annual study. The three weather variables analyzed were the seasonal running totals of air and soil temperature degree days (4.4°C basis, 30 cm above and 5 cm below ground level, respectively) and the frequency of precipitation events delivering at least .01 inches of water. All correlation coefficients were significant ($p = 0.0001$). Of the three litter species, the pine data was best correlated 1) with all three weather variables, 2) with both bulk and individual fascicle/leaf samples, and 3) on both hardwood stand and plantation subunits. For all three litter species, bulk sample mass loss was 1) more highly correlated with all three weather variables than was mass loss from individual fascicle/leaf samples and 2) (with very few exceptions) more highly correlated with all three weather variables in the hardwood stand than in the plantations. Of the three litter species, only individual maple leaves were more highly correlated with temperature-related weather variables in the plantation subunits than in the hardwood stand subunits. Overall, soil temperature degree days was only slightly better correlated with mass loss than was air temperature degree days. Based on this analysis, we have used seasonal running totals of air temperature degree days (ATDDRT) and soil temperature degree days (ST5DDRT), and the frequency of precipitation events delivering at least .01 inches of water (PR.01RT) as potential covariates in our preliminary efforts to explain differences in dry matter mass loss detected by 3-way ANOVA among years, sampling dates, and plantation or hardwood stand subunits.

ANACOV Results - Individual Fascicle/Leaf Samples

For each litter species, "initial" ANACOV included the three weather variables (ATDDRT, ST5DDRT, and PR.01RT) and initial leaf density for oak and maple. These initial ANACOVs are presented below. Additional ANACOVs using subsets of these four covariates were conducted. The ANACOVs presented below were

selected because they provide insight for explanation of significant differences detected by the 3-way ANOVAs discussed above.

Individual Pine Fascicles

Tables 42 and 43 present the "initial" ANACOV tables for detection of significant differences in individual pine fascicle dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 44 and 45 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANACOVs, respectively.

No significant differences were detected among the three study plantations, undoubtedly because this ANACOV raised the detectable differences associated with plantation subunit means to an unacceptable level (approximately 30 percent). Individual pine fascicles decomposed faster in the antenna hardwood stand than in the control hardwood stand. Comparing years in the plantations, 1986 and 1987 samples decomposed faster than 1985 samples; in the hardwood stands, 1985 samples decomposed faster than did the 1986 or 1987 samples. Significant monthly progress occurred in the plantations, while monthly progress in the hardwood stands was insignificant during August through October. Detectable differences were low, well below 2 percent of the yearly and subunit mean values (except for plantation subunits).

Tables 46 and 47 present the ANACOV tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively, using ATDDRT as the only covariate. Tables 48 and 49 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANACOVs, respectively.

No differences were detected in decomposition rate for individual pine fascicles among plantations, though decomposition was still faster in the antenna hardwood stand than in the control hardwood stand. Comparing years in the plantations, 1987

Table 42. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual pine needles in the three plantation subunits, using three covariates: running totals of 1) air temperature degree days (ATDDRT; 4.4°C basis), 2) soil temperature degree days (ST5DDRT; 5 cm depth), and 3) number of precipitation events exceeding .01 in. (PR.01RT).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	82	15.79	0.19	79.50	0.0001	0.82
Year	2		0.17	35.43	0.0001	
Month	6		0.03	1.82	0.0927	
Plantation	2		0.00	0.88	0.4135	
Location	69		0.25	1.47	0.0082	
ATDDRT	1		0.01	3.36	0.0671	
ST5DDRT	1		0.00	0.09	0.7705	
PR.01RT	1		0.17	71.59	0.0001	
Error	1412	3.42				
Corrected Total	1494	19.21				

Table 43. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual pine needles in the two hardwood stand subunits, using three covariates: running totals of 1) air temperature degree days (ATDDRT; 4.4°C basis), 2) soil temperature degree days (ST5DDRT; 5 cm depth), and 3) number of precipitation events exceeding .01 in. (PR.01RT).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	59	12.35		112.93	0.0001	0.86
Year	2		0.10	26.20	0.0001	
Month	7		0.20	15.78	0.0001	
Hardwood Stand	1		0.04	23.07	0.0001	
Location	46		0.24	2.77	0.0001	
ATDDRT	1		0.06	32.75	0.0001	
ST5DDRT	1		0.01	6.96	0.0084	
PR.01RT	1		0.01	4.16	0.0417	
Error	1119	2.07				
Corrected Total	1178	14.42				

Table 44. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 42.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year									5	6
1985	1.22	0.008	1.29	1985						
1986	1.15	0.008	1.36	1986					*	
1987	1.16	0.004	0.68	1987					*	
Month					1	2	3	4	5	6
May	1.17	0.037	6.20	May						
June	1.18	0.027	4.48	June	*					
July	1.17	0.014	2.35	July	*	*				
August	1.17	0.006	1.01	Aug	*	*	*			
September	1.18	0.020	3.32	Sept	*	*	*	*		
October	1.18	0.031	5.15	Oct	*	*	*	*	*	
November	1.19	0.035	5.76	Nov	*	*	*	*	*	*
Plantation							G		A	
Ground	1.17	0.173	28.98	Ground						
Antenna	1.18	0.181	30.06	Antenna						
Control	1.17	0.175	29.32	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 45. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 43.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year									5		6
1985	1.12	0.008	1.40	1985							
1986	1.17	0.008	1.34	1986					*		
1987	1.18	0.005	0.83	1987					*		
Month					1	2	3	4	5	6	7
May	1.07	0.025	4.58	May							
June	1.11	0.020	3.53	June	*						
July	1.14	0.012	2.06	July	*	*					
August	1.18	0.007	1.16	Aug	*	*	*				
September	1.18	0.012	1.99	Sept	*	*	*				
October	1.19	0.019	3.13	Oct	*	*					
November	1.18	0.022	3.65	Nov	*						
December	1.21	0.024	3.89	Dec	*	*	*			*	*
Hardwood Stand								A			
Antenna	1.14	0.005	0.86	Antenna							
Control	1.17	0.006	1.01	Control				*			

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 46. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual pine needles in the three plantation subunits, using the running totals of air temperature degree days (ATDDRT; 4.4°C basis) as the only covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	80	15.62		76.81	0.0001	0.81
Year	2		0.04	8.51	0.0002	
Month	6		0.17	11.11	0.0001	
Plantation	2		0.00	0.72	0.4886	
Location	69		0.26	1.49	0.0066	
ATDDRT	1		0.04	17.16	0.0001	
Error	1414	3.59				
Corrected Total	1494	19.21				

Table 47. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual pine needles in the two hardwood stand subunits, using the running total of air temperature degree days (ATDDRT; 4.4°C basis) as the only covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	57	12.32		115.11	0.0001	0.85
Year	2		0.68	180.88	0.0001	
Month	7		0.30	22.57	0.0001	
Hardwood Stand	1		0.03	16.85	0.0001	
Location	46		0.22	2.57	0.0001	
ATDDRT	1		0.13	68.70	0.0001	
Error	1121	2.10				
Corrected Total	1178	14.42				

Table 48. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 46.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6				
1985	1.18	0.007	1.16	1985						
1986	1.18	0.007	1.16	1986						
1987	1.15	0.004	0.68	1987	*	*				
Month					1	2	3	4	5	6
May	1.22	0.022	3.53	May						
June	1.21	0.016	2.59	June						
July	1.19	0.009	1.48	July	*	*				
August	1.18	0.006	1.00	Aug						
September	1.16	0.013	2.20	Sept				*		
October	1.13	0.019	3.30	Oct	*	*	*	*	*	
November	1.11	0.021	3.71	Nov	*	*	*	*	*	*
Plantation					G	A				
Ground	1.17	0.006	1.01	Ground						
Antenna	1.18	0.005	0.83	Antenna						
Control	1.17	0.006	1.01	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 49. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 47.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6					
1985	1.11	0.007	1.24	1985							
1986	1.18	0.007	1.16	1986	*						
1987	1.18	0.004	0.66	1987	*						
Month					1	2	3	4	5	6	7
May	1.08	0.025	4.54	May							
June	1.11	0.019	3.35	June	*						
July	1.14	0.011	1.89	July	*	*					
August	1.18	0.006	1.00	Aug	*	*	*				
September	1.18	0.012	1.99	Sept	*	*	*				
October	1.19	0.018	2.96	Oct	*	*					
November	1.18	0.020	3.32	Nov	*					*	
December	1.20	0.020	3.27	Dec	*	*	*				*
Hardwood Stand					C						
Antenna	1.15	0.005	0.85	Antenna							
Control	1.17	0.006	1.01	Control	*						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

samples decomposed faster than did 1985 or 1986 samples; in the hardwood stands, 1985 samples decomposed faster than did 1986 or 1987 samples. Significant monthly progress failed to occur in the plantations during May and July; no significant progress was made in the hardwood stands during August or September. Detectable differences were all low, below 2 percent for yearly and subunit mean values, and below 5 percent for monthly mean values.

Tables 50 and 51 present the ANACOV tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively, using PR.01RT as the only covariate. Tables 52 and 53 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANACOVs, respectively.

No differences in decomposition were detected among either the plantation or the hardwood stand subunits, though the detectable differences associated with the hardwood stand means were unacceptable (approximately 25 percent). Comparing years in the plantations, 1986 and 1987 samples decomposed faster than did the 1985 samples; in the hardwood stands, the 1985 samples decomposed faster than did the 1986 or 1987 samples. Monthly progress in the plantations occurred largely during June and August. Progress in the hardwood stands occurred during every month except May and November. Significant mass was actually gained during November. Detectable differences were low, below 3 percent except for those associated with hardwood stand subunit means.

Individual Oak Leaves

Tables 54 and 55 present the "initial" ANACOV tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 56 and 57 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANACOVs, respectively.

Among the study plantations, individual oak leaves decomposed faster at the ground and antenna plantations than at the

Table 50. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual pine needles in the three plantation subunits, using the number of precipitation events exceeding .01 in. (PR.01RT) as the only covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	80	15.77		81.16	0.0001	0.82
Year	2		0.34	69.16	0.0001	
Month	6		0.14	9.53	0.0001	
Plantation	2		0.01	2.31	0.1000	
Location	69		0.25	1.47	0.0085	
PR.01RT	1		0.20	82.93	0.0001	
Error	1414	3.44				
Corrected Total	1494	19.21				

Table 51. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual pine needles in the two hardwood stand subunits, using the number of precipitation events exceeding .01 in. (PR.01RT) as the only covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	57	12.24		110.20	0.0001	0.85
Year	2		0.03	6.57	0.0015	
Month	7		0.38	27.66	0.0001	
Hardwood Stand	1		0.00	1.02	0.3134	
Location	46		0.22	2.51	0.0001	
PR.01RT	1		0.05	25.31	0.0001	
Error	1121	2.18				
Corrected Total	1178	14.42				

Table 52. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 50.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6				
1985	1.22	0.008	1.29	1985						
1986	1.14	0.007	1.20	1986	*					
1987	1.16	0.003	0.51	1987	*					
Month					1	2	3	4	5	6
May	1.21	0.012	1.94	May						
June	1.21	0.010	1.62	June						
July	1.18	0.007	1.16	July	*	*				
August	1.17	0.005	0.84	Aug	*	*				
September	1.15	0.007	1.19	Sept	*	*	*	*		
October	1.15	0.011	1.87	Oct	*	*	*	*		
November	1.15	0.015	2.56	Nov	*	*				
Plantation					G	A				
Ground	1.17	0.006	1.01	Ground						
Antenna	1.18	0.005	0.83	Antenna						
Control	1.17	0.006	1.01	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 53. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 51.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6					
1985	1.13	0.008	1.39	1985							
1986	1.15	0.008	1.36	1986	*						
1987	1.16	0.003	0.51	1987	*						
Month					1	2	3	4	5	6	7
May	1.21	0.014	2.27	May							
June	1.21	0.011	1.78	June							
July	1.19	0.008	1.32	July	*	*					
August	1.17	0.006	1.01	Aug	*	*	*				
September	1.11	0.006	1.06	Sept	*	*	*	*			
October	1.09	0.010	1.80	Oct	*	*	*	*	*		
November	1.08	0.013	2.36	Nov	*	*	*	*	*	*	
December	1.12	0.017	2.98	Dec	*	*	*	*		*	*
Hardwood Stand											
Antenna	1.15	0.145	24.71	Antenna							
Control	1.15	0.150	25.57	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 54. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual oak leaves in the three plantation subunits, using four covariates: 1) initial leaf density (gm/cm^2), and running totals of 2) air temperature degree days (ATDDRT; 4.4°C basis), 3) soil temperature degree days (ST5DDRT; 5 cm depth), and 4) number of precipitation events exceeding .01 in. (PR.01RT).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	83	45.56		55.92	0.0001	0.74
Year	2		0.14	7.03	0.0009	
Month	6		0.37	6.26	0.0001	
Plantation	2		0.19	9.88	0.0001	
Location	69		0.96	1.41	0.0157	
Density	1		2.39	243.32	0.0001	
ATDDRT	1		0.34	34.92	0.0001	
ST5DDRT	1		0.13	13.18	0.0003	
PR.01RT	1		0.51	52.10	0.0001	
Error	1654	16.24				
Corrected Total	1737	61.80				

Table 55. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual oak leaves in the two hardwood stand subunits, using four covariates: 1) initial leaf density (gm/cm^2), and running totals of 2) air temperature degree days (ATDDRT; 4.4°C basis), 3) soil temperature degree days (ST5DDRT; 5 cm depth), and 4) number of precipitation events exceeding .01 in. (PR.01RT).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	60	21.19		69.89	0.0001	0.78
Year	2		0.03	3.20	0.0413	
Month	7		0.16	4.43	0.0001	
Hardwood Stand	1		0.01	1.37	0.2414	
Location	46		0.51	2.18	0.0001	
Density	1		1.04	205.70	0.0001	
ATDDRT	1		0.01	1.12	0.2894	
ST5DDRT	1		0.02	4.33	0.0377	
PR.01RT	1		0.05	9.44	0.0022	
Error	1154	5.83				
Corrected Total	1214	27.03				

Table 56. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 54.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6				
1985	1.12	0.015	2.63	1985						
1986	1.07	0.015	2.75	1986	*					
1987	1.06	0.007	1.29	1987	*					
Month					1	2	3	4	5	6
May	1.15	0.073	12.44	May						
June	1.09	0.054	9.71	June	*					
July	1.08	0.030	5.44	July						
August	1.06	0.011	2.03	Aug						
September	1.06	0.032	5.92	Sept						
October	1.06	0.054	9.98	Oct						
November	1.07	0.061	11.17	Nov						
Plantation					G	A				
Ground	1.07	0.011	2.01	Ground						
Antenna	1.06	0.010	1.85	Antenna						
Control	1.11	0.012	2.12	Control	*	*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 57. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 55.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6					
1985	1.13	0.013	2.25	1985							
1986	1.15	0.013	2.22	1986							
1987	1.16	0.007	1.18	1987	*						
Month					1	2	3	4	5	6	7
May	1.17	0.041	6.87	May							
June	1.16	0.032	5.41	June							
July	1.18	0.020	3.32	July							
August	1.16	0.011	1.86	Aug							
September	1.15	0.018	3.07	Sept							
October	1.12	0.029	5.08	Oct							
November	1.09	0.034	6.11	Nov				*	*	*	
December	1.13	0.037	6.42	Dec							*
Hardwood Stand					A						
Antenna	1.15	0.009	1.53	Antenna							
Control	1.14	0.009	1.55	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

control plantation; no difference was detected between the two hardwood stand subunits. Comparing years in the plantation subunits, 1986 and 1987 samples decomposed faster than did the 1985 samples; in the hardwood stands, 1985 samples decomposed faster than did the 1987 samples. Significant progress occurred only during May in the plantations, and during October and November in the hardwood stands. Significant mass was actually gained during November. Detectable differences were low (less than 3 percent) for yearly and subunit means, and acceptable (mostly below 10 percent) for monthly means.

Tables 58 and 59 present the ANACOV tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively, using PR.01RT as the only covariate. Tables 60 and 61 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANACOVs, respectively.

No differences in decomposition were detected among either the plantation or the hardwood stand subunits. Comparing years in the plantations, 1987 samples decomposed fastest and 1985 samples slowest; in the hardwood stands, no differences among years were detected. Significant monthly progress occurred only during May in the plantations, while significant progress was made in the hardwood stands during all months except June and November. Significant mass increase occurred in the hardwood stand subunits during November. Detectable differences were all low, below 2 percent for yearly and subunit mean values, and below 6 percent for monthly mean values.

Individual Maple Leaves

Tables 62 and 63 present the ANACOV tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively, using initial leaf density as the only covariate. Tables 64 and 65 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANACOVs, respectively.

Table 58. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual oak leaves in the three plantation subunits, using the number of precipitation events exceeding .01 in. (PR.01RT) as the only covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	80	42.87		46.91	0.0001	0.69
Year	2		0.84	36.68	0.0001	
Month	6		0.74	10.82	0.0001	
Plantation	2		0.05	2.16	0.1154	
Location	69		1.12	1.42	0.0144	
PR.01RT	1		0.70	61.66	0.0001	
Error	1657	18.93				
Corrected Total	1737	61.80				

Table 59. Covariance analysis table for detection of differences in dry matter mass loss (arcsine square root of the proportion of initial mass remaining) from individual oak leaves in the two hardwood stand subunits, using the number of precipitation events exceeding .01 in. (PR.01RT) as the only covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	57	20.12		59.07	0.0001	0.74
Year	2		0.02	1.99	0.1369	
Month	7		0.44	10.41	0.0001	
Hardwood Stand	1		0.00	0.40	0.5295	
Location	46		0.48	1.73	0.0021	
PR.01RT	1		0.04	7.07	0.0079	
Error	1158	6.92				
Corrected Total	1215	27.04				

Table 60. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 58.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6				
1985	1.13	0.014	2.43	1985						
1986	1.08	0.016	2.90	1986	*					
1987	1.01	0.005	0.97	1987	*	*				
Month					1	2	3	4	5	6
May	1.11	0.026	4.59	May						
June	1.07	0.021	3.85	June	*					
July	1.07	0.015	2.75	July	*					
August	1.05	0.011	2.05	Aug	*					
September	1.05	0.013	2.43	Sept						
October	1.08	0.022	3.99	Oct						
November	1.10	0.028	4.99	Nov					*	
Plantation					G	A				
Ground	1.08	0.011	2.00	Ground						
Antenna	1.06	0.011	2.03	Antenna						
Control	1.08	0.011	2.00	Control						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 61. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 59.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6					
1985	1.12	0.014	2.45	1985							
1986	1.14	0.013	2.24	1986							
1987	1.14	0.006	1.03	1987							
Month					1	2	3	4	5	6	7
May	1.24	0.024	3.79	May							
June	1.22	0.019	3.05	June	*						
July	1.21	0.014	2.27	July	*						
August	1.17	0.010	1.68	Aug	*	*	*				
September	1.12	0.011	1.92	Sept	*	*	*	*			
October	1.06	0.018	3.33	Oct	*	*	*	*	*		
November	1.02	0.023	4.42	Nov	*	*	*	*	*	*	
December	1.05	0.030	5.60	Dec	*	*	*	*	*		*
Hardwood Stand					A						
Antenna	1.14	0.009	1.55	Antenna							
Control	1.13	0.009	1.56	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ $\alpha = .05$, least squares means pairwise comparisons

Table 62. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual maple leaves in the three plantation subunits, using initial leaf density (gm/cm²) as the only covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	16	13.24		43.46	0.0001	0.46
Year	1		0.02	1.10	0.2935	
Month	6		11.63	101.80	0.0001	
Plantation	2		0.85	22.43	0.0001	
Location	6		0.47	4.15	0.0004	
Density	1		0.01	0.74	0.3887	
Error	819	15.60				
Corrected Total	835	28.84				

Table 63. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual maple leaves in the two hardwood stand subunits, using initial leaf density (gm/cm²) as the only covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	14	6.65		50.76	0.0001	0.52
Year	1		1.21	129.02	0.0001	
Month	7		4.25	64.83	0.0001	
Hardwood Stand	1		0.01	0.54	0.4645	
Location	4		0.06	1.67	0.1553	
Density	1		0.83	88.28	0.0001	
Error	646	6.05				
Corrected Total	660	12.70				

Table 64. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 62.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year						S				
1985	0.82	0.006	1.43	1985						
1986	0.83	0.010	2.36	1986						
Month					1	2	3	4	5	6
May	1.02	0.013	2.50	May						
June	0.95	0.013	2.68	June	*					
July	0.86	0.013	2.96	July	*	*				
August	0.81	0.013	3.15	Aug	*	*	*			
September	0.79	0.013	3.23	Sept	*	*	*			
October	0.68	0.013	3.75	Oct	*	*	*	*	*	
November	0.68	0.014	4.04	Nov	*	*	*	*	*	
Plantation							G		A	
Ground	0.79	0.009	2.23	Ground						
Antenna	0.82	0.009	2.15	Antenna			*			
Control	0.87	0.009	2.03	Control			*		*	

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 65. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 63.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year							5				
1985	0.89	0.004	0.88	1985							
1986	0.99	0.007	1.39	1986			*				
Month					1	2	3	4	5	6	7
May	1.06	0.011	2.03	May							
June	1.01	0.011	2.13	June	*						
July	1.01	0.011	2.13	July	*						
August	0.96	0.011	2.25	Aug	*	*	*				
September	0.92	0.011	2.34	Sept	*	*	*	*			
October	0.86	0.011	2.51	Oct	*	*	*	*	*		
November	0.82	0.011	2.63	Nov	*	*	*	*	*	*	
December	0.87	0.011	2.48	Dec	*	*	*	*	*		*
Hardwood Stand								A			
Antenna	0.94	0.006	1.25	Antenna							
Control	0.94	0.006	1.25	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Among the plantation subunits, decomposition progressed fastest in the ground plantation and slowest in the control plantation; no difference was detected between the hardwood stand subunits. Comparing years in the plantations, no difference in decomposition was detected between 1985 and 1986; in the hardwood stands, 1985 samples decomposed faster than did the 1986 samples. Significant monthly progress occurred in the plantations, except during August and October. Significant monthly progress occurred in the hardwood stands, except during June and November. Significant mass was gained during November in the hardwood stand subunits. Detectable differences were low, below 3 percent for yearly and subunit means and below 5 percent for monthly means.

Individual Filter Paper Disks

Tables 66 and 67 present the "initial" ANACOV tables for detection of sigificant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 68 and 69 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANACOVs, respectively. No significant differences among months or subunits were detected among either the plantations or the hardwood stands. This is undoubtedly due to the extraordinarily large detectable differences associated with this ANACOV.

ANACOV Results - Bulk Leaf Litter Samples

Bulk Pine Needle Litter

Tables 70 and 71 present the "initial" ANACOV tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively. Tables 72 and 73 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANACOVs, respectively.

Table 66. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual Whatman No. 1 filter paper disks in the three plantation subunits, using three covariates: running totals of 1) air temperature degree days (ATDDRT; 4.4°C basis), 2) soil temperature degree days (ST5DDRT; 5 cm depth), and 3) number of precipitation events exceeding .01 in. (PR.01RT).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	79	10.15		1.63	0.0028	0.36
Year	2		0.00	-.--	-.----	
Month	6		0.63	1.33	0.2454	
Plantation	2		0.22	1.39	0.2516	
Location	69		6.07	1.13	0.2471	
ATDDRT	1		0.02	0.31	0.5770	
ST5DDRT	1		0.00	0.02	0.8837	
PR.01RT	1		0.00	0.01	0.9206	
Error	225	17.71				
Corrected Total	304	27.86				

Table 67. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from individual Whatman No. 1 filter paper disks in the two hardwood stand subunits, using three covariates: running totals of 1) air temperature degree days (ATDDRT; 4.4°C basis), 2) soil temperature degree days (ST5DDRT; 5 cm depth), and 3) number of precipitation events exceeding .01 in. (PR.01RT).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	56	7.23		2.05	0.0002	0.86
Year	0		0.00	-.--	-.----	
Month	6		0.35	0.92	0.4809	
Hardwood Stand	1		0.02	0.27	0.6072	
Location	46		4.40	1.52	0.0295	
ATDDRT	1		0.00	0.00	0.9484	
ST5DDRT	1		0.00	0.07	0.7938	
PR.01RT	1		0.01	0.16	0.6925	
Error	178	11.23				
Corrected Total	234	18.47				

Table 68. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 66.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]
Year				
1987	1.02	0.227	44.	
Month				1 2 3 4 5 6
May	-0.06	2.213	7229.	May
June	-0.00	1.799	ERR	June
July	0.53	1.029	381.	July
August	1.01	0.270	52.	Aug
September	1.63	0.830	100.	Sept
October	2.02	1.413	137.	Oct
November	2.04	1.494	144.	Nov
Plantation				G A
Ground	0.99	0.217	43	Ground
Antenna	1.09	0.188	34	Antenna
Control	0.99	0.312	62	Control

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 69. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 67.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]
Year				
1987	0.79	0.383	95.	
Month				1 2 3 4 5 6
May	-0.37	1.964	1040.	May
June	-0.24	1.625	1327.	June
July	0.17	1.052	1213.	July
August	0.76	0.479	124.	Aug
September	1.42	0.351	48.	Sept
October	1.75	0.784	88.	Oct
November	2.06	1.239	118.	Nov
Hardwood Stand				A
Antenna	0.71	0.452	125.	Antenna
Control	0.87	0.370	83.	Control

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 70. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk pine needle samples in the three plantation subunits, using three covariates: running totals of 1) air temperature degree days (ATDDRT; 4.4°C basis), 2) soil temperature degree days (ST5DDRT; 5 cm depth), and 3) number of precipitation events exceeding .01 in. (PR.01RT).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	19	3.57		167.99	0.0001	0.90
Year	2		0.09	38.98	0.0001	
Month	6		0.02	3.57	0.0019	
Plantation	2		0.05	22.06	0.0001	
Location	6		0.01	1.73	0.1119	
ATDDRT	1		0.00	2.75	0.0983	
ST5DDRT	1		0.00	1.64	0.2009	
PR.01RT	1		0.01	7.83	0.0054	
Error	359	0.40				
Corrected Total	378	3.97				

Table 71. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk pine needle samples in the two hardwood stand subunits, using three covariates: running totals of 1) air temperature degree days (ATDDRT; 4.4°C basis), 2) soil temperature degree days (ST5DDRT; 5 cm depth), and 3) number of precipitation events exceeding .01 in. (PR.01RT).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	17	2.86		192.32	0.0001	0.93
Year	2		0.09	49.45	0.0001	
Month	7		0.01	2.41	0.0209	
Hardwood Stand	1		0.00	2.88	0.0910	
Location	4		0.00	0.74	0.5637	
ATDDRT	1		0.00	1.73	0.1902	
ST5DDRT	1		0.00	1.72	0.1910	
PR.01RT	1		0.00	0.26	0.6130	
Error	244	0.21				
Corrected Total	261	3.08				

Table 72. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 70.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6				
1985	1.12	0.006	1.05	1985						
1986	1.14	0.007	1.20	1986						
1987	1.18	0.005	0.83	1987	*	*				
Month					1	2	3	4	5	6
May	1.06	0.051	9.43	May						
June	1.07	0.038	6.96	June						
July	1.12	0.020	3.50	July	*	*				
August	1.16	0.005	0.84	Aug	*	*				
September	1.19	0.023	3.79	Sept		*				
October	1.21	0.039	6.32	Oct						
November	1.21	0.044	7.13	Nov						
Plantation					G	A				
Ground	1.13	0.003	0.52	Ground						
Antenna	1.16	0.009	0.52	Antenna	*					
Control	1.14	0.005	0.86	Control		*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 73. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 71.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6					
1985	1.09	0.007	1.26	1985							
1986	1.17	0.007	1.17	1986	*						
1987	1.17	0.006	1.01	1987	*						
Month					1	2	3	4	5	6	7
May	1.09	0.035	6.29	May							
June	1.09	0.027	4.86	June							
July	1.12	0.016	2.80	July		*					
August	1.15	0.007	1.19	Aug		*					
September	1.16	0.015	2.53	Sept							
October	1.17	0.025	4.19	Oct							
November	1.18	0.030	4.98	Nov							
December	1.20	0.032	5.23	Dec							
Hardwood Stand					C						
Antenna	1.14	0.004	0.69	Antenna							
Control	1.15	0.005	0.85	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Among the plantation subunits, bulk pine samples decomposed faster in the ground and control plantations than in the antenna plantation. No significant difference in decomposition was detected between the antenna and control hardwood stands. Comparing years in the plantations, 1985 and 1986 samples decomposed faster than did the 1987 samples; in the hardwood stands, 1985 samples decomposed fastest. Significant monthly progress occurred only during June in both the plantations and the hardwood stands. Detectable differences were very low (well below 2 percent) for yearly and subunit mean values, and acceptable (below 10 percent) for monthly mean values.

Tables 74 and 75 present the ANACOV tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively, using ST5DDRT as the only covariate. Tables 76 and 77 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANACOVs, respectively.

Among the plantations, bulk pine samples decomposed faster in the ground and control plantations than in the antenna plantation. No difference was detected between the rates of bulk pine sample decomposition in the antenna and control hardwood stands. Comparing years in the plantations, 1985 samples decomposed fastest and 1987 samples slowest; in the hardwood stands, 1985 samples decomposed faster than either the 1986 or 1987 samples. This ANACOV resulted in adjusted monthly means which increased as the field season progressed. However, monthly "progress" was significant only in the plantation subunits during June and July. Detectable differences were extremely low (below 1 percent) for yearly and subunit mean values, and acceptable (below 10 percent) for monthly means.

Bulk Oak Leaf Litter

Tables 78 and 79 present the ANACOV tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively, using ATDDRT as

Table 74. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk pine needle samples in the three plantation subunits, using the running total of soil temperature degree days (ST5DDRT; 5 cm depth, 4.4°C basis) as the covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	17	3.56		181.95	0.0001	0.90
Year	2		0.18	79.07	0.0001	
Month	6		0.06	8.21	0.0001	
Plantation	2		0.09	37.11	0.0001	
Location	6		0.01	1.69	0.1226	
ST5DDRT	1		0.03	22.15	0.0001	
Error	361	0.42				
Corrected Total	378	3.97				

Table 75. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk pine needle samples in the two hardwood stand subunits, using the running totals of soil temperature degree days (ST5DDRT; 5 cm depth, 4.4°C), as the covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	15	2.86		216.92	0.0001	0.93
Year	2		0.16	93.50	0.0001	
Month	7		0.01	2.01	0.0548	
Hardwood Stand	1		0.00	1.29	0.2571	
Location	4		0.00	0.74	0.5685	
ST5DDRT	1		0.03	31.40	0.0001	
Error	246	0.22				
Corrected Total	261	3.08				

Table 76. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 74.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6				
1985	1.11	0.004	0.67	1985						
1986	1.16	0.003	0.59	1986	*					
1987	1.17	0.003	0.51	1987	*	*				
Month					1	2	3	4	5	6
May	1.05	0.049	9.07	May						
June	1.07	0.036	6.59	June						
July	1.12	0.019	3.29	July	*	*				
August	1.17	0.005	0.82	Aug	*	*	*			
September	1.20	0.023	3.72	Sept	*	*				
October	1.21	0.037	5.99	Oct						
November	1.21	0.041	6.67	Nov						
Plantation					G	A				
Ground	1.14	0.003	0.53	Ground						
Antenna	1.17	0.003	0.53	Antenna	*					
Control	1.13	0.003	0.54	Control		*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 77. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 75.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6					
1985	1.09	0.003	0.57	1985							
1986	1.17	0.005	0.80	1986	*						
1987	1.17	0.005	0.87	1987	*						
Month					1	2	3	4	5	6	7
May	1.12	0.031	5.43	May							
June	1.11	0.024	4.28	June							
July	1.13	0.015	2.85	July							
August	1.15	0.005	0.86	Aug							
September	1.15	0.014	2.35	Sept							
October	1.16	0.023	3.93	Oct							
November	1.16	0.027	4.49	Nov							
December	1.18	0.026	4.30	Dec							
Hardwood Stand					C						
Antenna	1.14	0.003	0.50	Antenna							
Control	1.15	0.004	0.71	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 78. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk oak leaf samples in the three plantation subunits, using the running total of air temperature degree days (ATDDRT; 4.4°C basis) as the only covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	17	4.90		76.11	0.0001	0.78
Year	2		0.04	5.77	0.0034	
Month	6		0.12	5.27	0.0001	
Plantation	2		0.02	2.96	0.0532	
Location	6		0.03	1.27	0.2705	
ATDDRT	1		0.00	0.21	0.6471	
Error	363	1.37				
Corrected Total	380	6.27				

Table 79. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk oak leaf samples in the two hardwood stand subunits, using the running total of air temperature degree days (ATDDRT; 4.4°C basis) as the only covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	15	4.37		141.76	0.0001	0.90
Year	2		0.22	52.72	0.0001	
Month	7		0.24	16.56	0.0001	
Hardwood Stand	1		0.00	0.54	0.4618	
Location	4		0.01	0.70	0.5893	
ATDDRT	1		0.04	17.09	0.0001	
Error	248	0.51				
Corrected Total	263	4.88				

Table 80. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 78.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year									5	6
1985	1.13	0.008	1.39	1985						
1986	1.17	0.006	1.01	1986					*	
1987	1.16	0.007	1.18	1987					*	
Month					1	2	3	4	5	6
May	1.34	0.052	7.61	May						
June	1.28	0.039	5.97	June	*					
July	1.23	0.022	3.51	July	*	*				
August	1.16	0.009	1.52	Aug	*	*	*			
September	1.08	0.026	4.72	Sept	*	*	*	*		
October	1.01	0.039	7.57	Oct	*	*	*	*	*	
November	0.97	0.043	8.69	Nov	*	*	*	*	*	*
Plantation							G		A	
Ground	1.14	0.006	1.03	Ground						
Antenna	1.15	0.006	1.02	Antenna						
Control	1.17	0.006	1.01	Control			*		*	

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 81. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 79.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year							5		6		
1985	1.13	0.005	0.87	1985							
1986	1.21	0.007	1.13	1986			*				
1987	1.19	0.009	1.48	1987			*		*		
Month					1	2	3	4	5	6	7
May	1.12	0.052	9.10	May							
June	1.15	0.039	6.65	June							
July	1.18	0.022	3.65	July							
August	1.23	0.008	1.27	Aug	*						
September	1.23	0.023	3.67	Sept							
October	1.19	0.037	6.09	Oct							
November	1.20	0.041	6.70	Nov							
December	1.12	0.041	7.18	Dec				*	*	*	*
Hardwood Stand							A				
Antenna	1.18	0.004	0.66	Antenna							
Control	1.17	0.007	1.17	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

the only covariate. Tables 80 and 81 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANACOVs, respectively.

No significant differences were detected among either the plantation or the hardwood stand subunits. Comparing years in the plantations, 1985 samples decomposed faster than did either 1986 or 1987 samples; in the hardwood stands, 1985 samples decomposed fastest and 1986 samples slowest. Significant monthly progress occurred in the plantations; in the hardwood stands, significant monthly progress occurred only in November. Detectable differences were very low (well below 2 percent) for yearly and subunit mean values, and acceptable (below 10 percent) for monthly mean values.

Tables 82 and 83 present the ANACOV tables for detection of significant differences in dry matter mass loss for the plantation and hardwood stand subunits, respectively, using ST5DDRT as the only covariate. Tables 84 and 85 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANACOVs, respectively.

Among the plantations, bulk oak samples decomposed faster in the ground and antenna plantations than in the control plantation; in the hardwood stands, decomposition was faster in the control stand than in the antenna stand. No significant differences were detected among years in the plantation subunits, while 1985 samples in the hardwood stands decomposed fastest and 1986 samples slowest. Significant monthly progress ocurred in the plantation subunits. In the hardwood stands, significant monthly progress occurred only during November. Detectable differences were very low (well below 2 percent) for yearly and subunit mean values, and acceptable (below 10 percent) for monthly means in the hardwood stand subunits.

Bulk Maple Leaf Litter

Tables 86 and 87 present the ANACOV tables for detection of significant differences in dry matter mass loss for the planta-

Table 82. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk oak leaf samples in the three plantation subunits, using the running total of soil temperature degree days (ST5DDRT; 5 cm depth, 4.4°C basis) as the covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	17	4.91		77.20	0.0001	0.78
Year	2		0.02	2.56	0.0788	
Month	6		0.11	5.03	0.0001	
Plantation	2		0.05	6.55	0.0016	
Location	6		0.03	1.27	0.2711	
ST5DDRT	1		0.02	4.25	0.0400	
Error	363	1.36				
Corrected Total	1737	61.80				

Table 83. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk oak leaf samples in the two hardwood stand subunits, using the running total of soil temperature degree days (ST5DDRT; 5 cm depth, 4.4°C basis) as the covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	15	4.37		142.15	0.0001	0.90
Year	2		0.20	49.66	0.0001	
Month	7		0.18	12.66	0.0001	
Hardwood Stand	1		0.01	4.22	0.0410	
Location	4		0.01	0.71	0.5881	
ST5DDRT	1		0.04	17.74	0.0001	
Error	248	0.51				
Corrected Total	263	4.88				

Table 84. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 82.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6				
1985	1.14	0.007	1.20	1985						
1986	1.16	0.006	1.01	1986	*					
1987	1.16	0.005	0.84	1987	*					
Month					1	2	3	4	5	6
May	1.49	0.087	11.44	May						
June	1.40	0.064	8.96	June	*					
July	1.29	0.034	5.17	July	*	*				
August	1.16	0.009	1.52	Aug	*	*	*			
September	1.01	0.040	7.76	Sept	*	*	*	*		
October	0.89	0.066	14.53	Oct	*	*	*	*	*	
November	0.84	0.073	17.03	Nov	*	*	*	*	*	*
Plantation					G	A				
Ground	1.15	0.006	1.02	Ground						
Antenna	1.15	0.006	1.02	Antenna						
Control	1.17	0.006	1.01	Control	*	*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 85. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 83.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6					
1985	1.13	0.005	0.87	1985							
1986	1.22	0.007	1.12	1986	*						
1987	1.19	0.008	1.32	1987	*	*					
Month					1	2	3	4	5	6	7
May	1.14	0.047	8.08	May							
June	1.16	0.037	6.25	June							
July	1.18	0.022	3.65	July							
August	1.22	0.008	1.29	Aug							
September	1.22	0.021	3.37	Sept							
October	1.19	0.035	5.76	Oct							
November	1.20	0.040	6.53	Nov							
December	1.11	0.039	6.89	Dec				*	*	*	*
Hardwood Stand					A						
Antenna	1.18	0.004	0.66	Antenna							
Control	1.17	0.006	1.01	Control	*						

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 86. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk maple leaf samples in the three plantation subunits, using running totals of the number of precipitation events exceeding .01 in. (PR.01RT) as the only covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	17	6.17		79.52	0.0001	0.79
Year	2		1.19	130.69	0.0001	
Month	6		0.12	4.21	0.0004	
Plantation	2		0.15	16.62	0.0001	
Location	6		0.10	3.62	0.0017	
PR.01RT	1		0.00	0.01	0.9295	
Error	359	1.64				
Corrected Total	376	7.80				

Table 87. Covariance analysis table for detection of differences in dry matter mass loss (arcsin square root of the proportion of initial mass remaining) from bulk maple leaf samples in the two hardwood stand subunits, using running totals of the number of precipitation events exceeding .01 in. (PR.01RT) as the covariate.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	15	3.83		151.91	0.0001	0.90
Year	2		1.07	318.91	0.0001	
Month	7		0.08	6.39	0.0001	
Hardwood Stand	1		0.00	0.07	0.7920	
Location	4		0.01	1.73	0.1431	
PR.01RT	1		0.00	1.19	0.2762	
Error	247	0.42				
Corrected Total	262	4.24				

Table 88. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 86.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6				
1985	0.83	0.010	2.36	1985						
1986	0.97	0.013	2.63	1986	*					
1987	0.99	0.007	1.39	1987	*					
Month					1	2	3	4	5	6
May	1.08	0.033	5.99	May						
June	1.03	0.026	4.95	June	*					
July	0.98	0.016	3.20	July	*	*				
August	0.93	0.010	2.11	Aug	*	*	*			
September	0.87	0.014	3.15	Sept	*	*	*	*		
October	0.82	0.027	6.45	Oct	*	*	*	*	*	
November	0.78	0.037	9.30	Nov	*	*	*	*	*	*
Plantation					G	A				
Ground	0.91	0.006	1.29	Ground						
Antenna	0.92	0.006	1.28	Antenna						
Control	0.96	0.006	1.23	Control	*	*				

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 89. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 87.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]							
Year					5	6					
1985	0.88	0.009	2.00	1985							
1986	1.07	0.008	1.47	1986	*						
1987	1.06	0.007	1.29	1987	*						
Month					1	2	3	4	5	6	7
May	1.15	0.026	4.43	May							
June	1.11	0.021	3.71	June	*						
July	1.10	0.013	2.32	July	*						
August	1.04	0.008	1.51	Aug	*	*	*				
September	0.98	0.009	1.80	Sept	*	*	*	*			
October	0.92	0.018	3.83	Oct	*	*	*	*	*		
November	0.88	0.025	5.57	Nov	*	*	*	*	*	*	
December	0.86	0.034	7.75	Dec	*	*	*	*	*	*	
Hardwood Stand					A						
Antenna	1.00	0.004	0.78	Antenna							
Control	1.00	0.004	0.78	Control							

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

tion and hardwood stand subunits, respectively, using PR.01RT as the only covariate. Tables 88 and 89 present the comparative statistics for the treatments corresponding to the plantation and hardwood stand subunit ANACOVs, respectively.

Among the plantation subunits, decomposition was faster in the antenna and ground plantations than in the control plantation; no difference was detected between the two hardwood stands. Comparing years in the plantations, 1985 samples decomposed faster than did either the 1986 or 1987 samples; in the hardwood stands, 1985 samples also decomposed faster than either the 1986 or 1987 samples. Significant monthly progress occurred in the plantations; in the hardwood stands, significant progress occurred monthly except during June and November. Detectable differences were very low (below 3 percent) for yearly and subunit mean values, and acceptable (below 10 percent) for monthly mean values.

ANACOV Results - Summary

The following outline summarizes the most useful results obtained to date from ANACOV on transformed dry matter mass loss data.

I. Subunits
   A. Plantations
      1. Pine
         a. No differences were found using individual fascicles, with either ATDDRT or PR.01RT as the only covariate.
         b. Bulk samples in the ground or control plantations decomposed faster than those in the antenna plantation, using either ST5DDRT or all three weather variables as covariates.
      2. Oak
         a. No differences were found using individual leaves, with PR.01RT as the only covariate.
         b. No differences were found using bulk samples, with ATDDRT as the only covariate.
      3. Maple
         a. Individual leaves decomposed fastest in the ground plantation and slowest in the control plantation, with initial leaf density as the only covariate.

b. Bulk samples decomposed faster in the ground and antenna plantations than in the control plantation, with PR.01RT as the only covariate.

B. Hardwood Stands
  1. Pine
    a. Individual fascicles decomposed faster in the antenna plantation than in the control plantation, with ATDDRT as the only covariate.
    b. No differences were found using bulk samples, with ST5DDRT as the only covariate.
  2. Oak
    a. No differences were found using individual leaves, with PR.01RT as the only covariate.
    b. No differences were found using bulk samples, with ATDDRT as the only covariate.
  3. Maple
    a. No differences were found using individual leaves, with initial leaf density as the only covariate.
    b. No difference was found using bulk samples, with PR.01RT as the only covariate.

II. Years
  A. Plantations
    1. Pine
      a. Individual fascicles decomposed faster in 1987 than in either 1985 or 1986, with ATDDRT as the only covariate. Decomposition was faster in both 1986 and 1987 than in 1985, with PR.01RT as the only covariate.
      b. Bulk samples decomposed faster in 1985 and 1986 than in 1987, using all three weather variables as covariates.
    2. Oak
      a. Individual leaves decomposed faster in 1987 and 1986 than in 1985, using all three weather variables and initial leaf density as covariates.
      b. No differences were found using bulk samples, with ST5DDRT as the only covariate.
    3. Maple
      a. No difference was detected between 1985 and 1986 using individual leaves, with initial leaf density as the only covariate.
      b. Bulk samples decomposed faster during 1985 than in either 1986 or 1987, with PR.01RT as the only covariate.
  B. Hardwood Stands
    1. Pine
      a. Individual fascicles decomposed faster in 1985 than in either 1986 or 1987, with either ATDDRT or PR.01RT as the only covariate.
      b. Bulk samples decomposed faster in 1985 than in either 1986 or 1987, with ST5DDRT as the only covariate.

2. Oak
   a. No difference was found using individual leaves, with PR.O1RT as the only covariate.
   b. Bulk samples decomposed fastest in 1985 and slowest in 1986, with ATDDRT as the only covariate.
3. Maple
   a. Individual leaves decomposed faster in 1985 than in 1986, with initial leaf density as the only covariate.
   b. Bulk samples decomposed faster in 1985 than in either 1986 or 1987, with PR.O1RT as the only covariate.

The only case from above where our best ANACOV to date has indicated a significant difference which was not found with ANOVA is I.B.1.a. In 13 additional cases, our best ANACOV to date detected the same differences found with ANOVA. In the remaining 10 cases our best ANACOV to date explained differences detected by ANOVA without causing unacceptably large minimum detectable differences.

Individual pine fascicle mass loss in the plantation subunits appears to be best explained by either ATDDRT or PR.O1RT in separate ANACOVs. In either case, no differences among plantations were detected, but pine fascicles appear to have decomposed faster in 1987 than in 1985. Bulk pine mass loss in the plantations was best explained by ANACOV with ATDDRT, ST5DDRT and PR.O1RT included simultaneously. Decomposition is apparently slower in the antenna plantation than in the ground or control plantations, and appears to have proceeded at a faster pace in 1985 and 1986 than in 1987.

No difference in individual pine fascicle mass loss between the hardwood stand subunits was detected by ANOVA. Using either ATDDRT or PR.O1RT as a covariate, ANACOV detected faster decomposition in 1985 than in either 1986 or 1987. No difference in bulk pine mass loss between the hardwood stands was detected by either ANOVA or ANACOV with ST5DDRT as covariate. Both of these analyses, however, detected faster decomposition in 1985 than in 1986 or 1987.

Differences in individual oak leaf mass loss among the plantation subunits were explained either by ANOVA or by ANACOV

with PR.01RT as covariate. Using ANACOV with ATDDRT, ST5DDRT and PR.01RT as covariates simultaneously, oak leaves in the plantations appear to have decomposed slower in 1985 than in 1986 or 1987. Differences in bulk oak decomposition among plantations were explained using ANACOV with ATDDRT as covariate; differences among years were explained by ANACOV with ST5DDRT as covariate.

No difference in individual oak leaf mass loss was detected between the two hardwood stands, either by ANOVA or by ANACOV with PR.01RT as covariate. ANACOV with PR.01RT as covariate explained mass loss differences among years. Differences in bulk oak mass loss between the hardwood stands were explained using ANACOV with ATDDRT as covariate. Bulk sample mass loss appears to have been fastest in 1985 and slowest in 1987, based on ANOVA as well as ANACOV with ATDDRT as covariate.

Individual maple leaf mass loss in the plantation subunits apparently occurred fastest in the ground plantation and slowest in the control plantation, based both on ANOVA and ANACOV with initial leaf density as covariate. Neither analysis detected any differences among years in the plantations. Bulk maple samples apparently decomposed faster in the ground and antenna plantations than in the control plantation, based on ANOVA and ANACOV with PR.01RT as covariate. Both analyses indicated that bulk samples lost mass faster in 1985 than either 1986 or 1987.

No difference in individual maple leaf mass loss was detected between the hardwood stands by ANACOV with initial leaf density as covariate. However, individual maple leaf decomposition appears to have proceeded faster in 1985 than in 1986, based on both ANOVA and ANACOV with initial leaf density as covariate. Neither ANOVA nor ANACOV, with PR.01RT as covariate, detected any difference in bulk maple mass loss between the hardwood stands, but both analyses indicated that decomposition proceeded faster in 1985 than in either 1986 or 1987.

Results to date indicate that decomposition of all sample types in the hardwood stand subunits proceeded at least as fast in 1985 as in either 1986 or 1987. The same is the case for bulk samples of all three species in the plantation subunits. Future

ANACOV will focus in part on attempting to find some logical covariate(s) to explain this relationship among study years. We will also attempt to identify covariates to explain why individual pine and oak fascicles/leaves in the plantations decomposed faster in 1986 and/or 1987 than in 1985.

We suspect that the apparently faster mass loss from some sample sets during 1985 may be partly due to the earlier disbursal date for samples in the 1984/85 experiment (3 December 1984), compared to subsequent years (15 December 1985, 13 December 1986, and 12 December 1987). We have endeavored to disburse litter samples into the field as early each year as possible. Together with minor differences among years in monthly retrieval dates, corresponding samples spent 13 more days in the field on average in the 1984/85 experiment than in the 1985/86 experiment, 17 more days than in the 1986/87 experiment, and 11 more days than planned for the 1987/88 experiment. Even though the extra field time in the 1984/85 experiment occurred mainly at the beginning of the experiment (during the first half of December when little mass loss progress is expected), data plots indicate that some of the sets of samples retrieved at the beginning of the 1985 field season had lost more mass than had corresponding samples retrieved at the beginning of the 1986 or 1987 field seasons. Such differences were much more noticeable for maple samples than for pine or oak samples, and are apparent for pine and oak samples only in the hardwood stand subunits.

At present, and as expected, for all three species we have a better understanding of factors influencing mass loss progress in the hardwood stands than in the plantations. Pine needle decomposition appears to be largely independent of weather differences between the hardwood stands, though some yet unidentified factor(s) appear capable of affecting rates among years. Individual oak leaf and bulk oak leaf litter decomposition was best explained by frequency of precipitation events and air temperature, respectively. Again, some unidentified factor(s) appear capable of affecting decomposition rates among years. Individual maple leaf and bulk maple decomposition rates between hardwood

stands are adequately explained by initial leaf density and frequency of precipitation events, respectively. The same factor(s) affecting annual rates of pine and oak decomposition in hardwood stands is presumed to be influencing maple mass loss.

Nutrient Content of Bulk Standards

The random samples drawn from the pine, oak, and maple parent litter collections during the course of field sample preparation are referred to as bulk standards. These samples are used to estimate the initial condition of the litter comprizing the field samples. The percent of N, P, K, Ca, Mg and ash in the bulk standard subsamples on which each annual study is based are presented in Tables 90 - 95. One-way ANOVA tables for detection of differences among years in ash, N, P, K, Ca, and Mg content of the annual pine parent litter collections are presented as Tables 96 - 101, respectively. Corresponding ANOVA tables for the oak and maple parent collections are presented as Tables 102 - 107 and 108 - 113, respectively.

The pine litter collected for the 1984-85 study contained approximately 40 and 18 percent more N and Ca, respectively, than the parent collection for the 1985-86 study (α = .05). The oak parent collection used in the 1984-85 study contained approximately 24 and 17 percent less N and K, respectively, than the parent collection for the 1985-86 study, but also approximately 5 and 8 percent more Ca and Mg, respectively. The maple collection used in the 1984-85 study contained approximately 52, 35, and 11 percent less N, P, and Ca, respectively, than did the parent collection used in the 1985-86 study, but also approximately 111 percent more K. As soon as the nutrient status of the 1986-87 parent collections is known, we will test the percent initial N, P, K, Ca, and Mg content of our parent litter collections as covariates to help explain differences among years in decomposition rate for each litter species.

Table 90. Percent nitrogen content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984, 1985, and 1986 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985
Pine	1984	0.496	10	0.016		
	1985	0.429	16	0.013	*	
	1986	0.309	15	0.013	*	*
Oak	1985	0.637	15	0.031		
	1986	0.835	17	0.030		*
Maple	1985	0.537	15	0.050		
	1986	1.115	16	0.048		*

a/ α = .05, Tukey's H.S.D.

Table 91. Percent phosphorus content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984, 1985, and 1986 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985
Pine	1984	0.054	10	0.002		
	1985	0.037	16	0.002	*	
	1986	0.048	15	0.002		*
Oak	1985	0.071	15	0.004		
	1986	0.083	17	0.004		
Maple	1985	0.080	15	0.006		
	1986	0.124	16	0.006		*

a/ α = .05, Tukey's H.S.D.

Table 92. Percent potassium content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984, 1985, and 1986 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985
Pine	1984	0.413	10	0.020		
	1985	0.083	15	0.016	*	
	1986	0.059	15	0.016	*	
Oak	1985	0.119	15	0.004		
	1986	0.144	17	0.004		*
Maple	1985	0.449	15	0.011		
	1986	0.212	16	0.010		*

a/ α = .05, Tukey's H.S.D.

Table 93. Percent calcium content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984, 1985, and 1986 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	1985
Pine	1984	0.592	10	0.014		
	1985	0.412	15	0.012	*	
	1986	0.350	15	0.012	*	*
Oak	1985	1.036	15	0.017		
	1986	0.984	17	0.016		*
Maple	1985	0.925	15	0.032		
	1986	1.041	16	0.031		*

a/ α = .05, Tukey's H.S.D.

Table 94. Percent magnesium content of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984, 1985, and 1986 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	Differences[a] 1985
Pine	1984	0.111	10	0.004		
	1985	0.081	15	0.003	*	
	1986	0.083	15	0.003	*	
Oak	1985	0.126	15	0.002		
	1986	0.117	17	0.002		*
Maple	1985	0.137	15	0.004		
	1986	0.130	16	0.004		

a/ α = .05, Tukey's H.S.D.

Table 95. Percent ash weight of standards sampled from the parent litter collections of red pine, red oak and red maple corresponding to samples retrieved during the 1984, 1985, and 1986 field seasons.

Litter Species	Year	Mean Percent	Sample Size	Standard Error	Differences[a] 1984	Differences[a] 1985
Pine	1984	0.047	10	0.004		
	1985	0.032	15	0.003	*	
	1986	0.035	15	0.003		
Oak	1985	0.092	15	0.003		
	1986	0.079	17	0.003		*
Maple	1985	0.107	15	0.004		
	1986	0.111	16	0.004		

a/ α = .05, Tukey's H.S.D.

Table 96. ANOVA table for detection of differences in ash mass among the pine litter parent collections used in the 1983-1984, 1984-1985, and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	2	0.0015	0.0007	4.93	0.0125
Within Groups	38	0.0056	0.0001		
Total	40	0.0071			

Table 97. ANOVA table for detection of differences in nitrogen mass among the pine litter parent collections used in the 1983-1984, 1984-1985, and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	2	0.2304	0.1152	42.92	0.0001
Within Groups	38	0.1020	0.0027		
Total	40	0.3323			

Table 98. ANOVA table for detection of differences in phosphorus mass among the pine litter parent collections used in the 1983-1984, 1984-1985, and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	2	0.0020	0.0010	20.93	0.0001
Within Groups	38	0.0018	0.0000		
Total	40	0.0039			

Table 99. ANOVA table for detection of differences in potassium mass among the pine litter parent collections used in the 1983-1984, 1984-1985, and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	2	0.8795	0.4397	109.71	0.0001
Within Groups	37	0.1483	0.0040		
Total	39	1.0278			

Table 100. ANOVA table for detection of differences in calcium mass among the pine litter parent collections used in the 1983-1984, 1984-1985 and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	2	0.3616	0.1808	90.39	0.0001
Within Groups	37	0.0740	0.0020		
Total	39	0.4357			

Table 101. ANOVA table for detection of differences in magnesium mass among the pine litter parent collections used in the 1983-1984, 1984-1985, and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	2	0.0065	0.0032	24.45	0.0001
Within Groups	37	0.0049	0.0001		
Total	39	0.0115			

Table 102. ANOVA table for detection of differences in ash mass among the oak litter parent collections used in the 1984-1985 and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	1	0.0013	0.0013	9.16	0.0050
Within Groups	30	0.0041	0.0001		
Total	31	0.0054			

Table 103. ANOVA table for detection of differences in nitrogen mass among the oak litter parent collections used in the 1984-1985 and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	1	0.3121	0.3121	21.06	0.0001
Within Groups	30	0.4445	0.0148		
Total	31	0.7565			

Table 104. ANOVA table for detection of differences in phosphorus mass among the oak litter parent collections used in the 1984-1985 and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	1	0.0010	0.0010	3.77	0.0615
Within Groups	30	0.0079	0.0003		
Total	31	0.0089			

Table 105. ANOVA table for detection of differences in potassium mass among the oak litter parent collections used in the 1984-1985 and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	1	0.0048	0.0048	18.87	0.0001
Within Groups	30	0.0077	0.0003		
Total	31	0.0125			

Table 106. ANOVA table for detection of differences in calcium mass among the oak litter parent collections used in the 1984-1985 and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	1	0.0216	0.0216	5.17	0.0304
Within Groups	30	0.1254	0.0042		
Total	31	0.1470			

Table 107. ANOVA table for detection of differences in magnesium mass among the oak litter parent collections used in the 1984-1985 and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	1	0.0006	0.0006	9.64	0.0041
Within Groups	30	0.0020	0.0001		
Total	31	0.0026			

Table 108. ANOVA table for detection of differences in ash mass among the maple litter parent collections used in the 1984-1985 and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	1	0.0001	0.0001	0.42	0.5237
Within Groups	29	0.0083	0.0003		
Total	30	0.0084			

Table 109. ANOVA table for detection of differences in nitrogen mass among the maple litter parent collections used in the 1984-1985 and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	1	2.5898	2.5898	69.18	0.0001
Within Groups	29	1.0857	0.0374		
Total	30	3.6755			

Table 110. ANOVA table for detection of differences in phosphorus mass among the maple litter parent collections used in the 1984-1985 and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	1	0.0145	0.0145	25.59	0.0001
Within Groups	29	0.0164	0.0006		
Total	30	0.0309			

Table 111. ANOVA table for detection of differences in potassium mass among the maple litter parent collections used in the 1984-1985 and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	1	0.4349	0.4349	261.51	0.0001
Within Groups	29	0.0482	0.0017		
Total	30	0.4831			

Table 112. ANOVA table for detection of differences in calcium mass among the maple litter parent collections used in the 1984-1985 and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	1	0.1032	0.1032	6.56	0.0159
Within Groups	29	0.4560	0.0157		
Total	30	0.5592			

Table 113. ANOVA table for detection of differences in magnesium mass among the maple litter parent collections used in the 1984-1985 and 1985-1986 field studies.

Source of Variation	df	SS	MS	F	Signif. of F
Between Groups	1	0.0003	0.0003	1.28	0.2678
Within Groups	29	0.0068	0.0002		
Total	30	0.0071			

Nutrient Flux

Nutrient flux involved with bulk sample decomposition for each litter species has been determined for the 1984-85 and 1985-86 studies. For analysis, the N, P, K, Ca, Mg, and ash contents of retrieved litter samples are expressed as the proportion (X) of their original mass remaining at the time of sample retrieval. Bulk samples from the 1986-87 study are being ground for analysis. The nitrogen flux data for pine, oak and maple in the 1985-86 study are presented in Tables 114 - 116; analogous data for phosphorus are presented in Tables 117 - 119, for potassium in Tables 120 - 122, for calcium in Tables 123 - 125, for magnesium in Tables 126 - 128, and for ash in Tables 129 -131. The nitrogen flux patterns for the three litter species are compared for each subunit in Figures 49 - 53; analogous representations of the data for the other elements are presented in Figures 54 - 58 for phosphorus, 59 - 63 for potassium, 64 - 68 for calcium, and 69 - 73 for magnesium.

The patterns of nutrient flux and dry matter mass loss associated with pine, oak and maple litter demonstrate that these three litter species differ markedly in decomposition strategy.

1) The pattern of dry matter mass loss for oak litter has much more in common with that of pine than with that of maple.

2) The pattern of nitrogen flux for oak litter in 1986 had more in common with that of maple than with that of pine (Figures 49 - 53).

3) The pattern of phosphorus flux for oak litter in 1986 appeared to be intermediate between those of pine and maple (Figures 54 - 58).

4) The pattern of potassium flux for oak litter during 1986 was unique (Figures 59 - 63).

5) The patterns of calcium and magnesium flux for maple litter during 1986 was intermediate between those of pine and maple (Figures 64 - 68 and 69 - 73).

These patterns of similarities and differences between the three litter species are undoubtedly based on clear differences in

Table 114. Mean proportion[a] of initial total nitrogen mass remaining at different times in 1986, for bulk red pine foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.46	0.03	6	0.42	0.04	10
3 June	0.43	0.02	5	0.43	0.01	3
1 July	0.46	0.03	8	0.45	0.03	7
30 July	0.48	0.05	10	0.44	0.03	7
4 September	0.51	0.02	5	0 48	0.01	3
1 October	0.31	0.02	7	0.30	0.04	14
6 November	0.44	0.07	16	0.44	0.04	9
6 December				0.76	0.06	7

Table 114. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.43	0.04	9	0.44	0.05	12
3 June	0.41	0.02	6	0.42	0.02	6
1 July	0.46	0.04	9	0.45	0.04	10
30 July	0.46	0.03	7	0.43	0.03	7
4 September	0.51	0.05	10	0.50	0.04	9
1 October	0.40	0.05	13	0.41	0.02	5
6 November	0.45	0.06	15	0.41	0.06	15
6 December				0.87	0.06	6

Table 114. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.43	0.02	4
3 June	0.48	0.04	9
1 July	0.52	0.03	5
30 July	0.46	0.05	11
4 September	0.56	0.04	7
1 October	0.38	0.07	18
6 November	0.43	0.03	7
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent N content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 115. Mean proportion[a] of initial total nitrogen mass remaining at different times in 1986, for bulk red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.71	0.06	9	0.71	0.07	10
3 June	0.69	0.05	7	0.67	0.04	6
1 July	0.74	0.06	8	0.76	0.08	10
30 July	0.73	0.05	7	0.73	0.05	8
4 September	0.74	0.08	12	0.75	0.04	6
1 October	0.75	0.09	13	0.83	0.05	6
6 November	0.71	0.05	7	0.77	0.04	5
6 December				0.45	0.10	20

Table 115. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.65	0.05	7	0.63	0.03	6
3 June	0.68	0.03	5	0.76	0.04	5
1 July	0.72	0.03	4	0.75	0.05	7
30 July	0.80	0.07	9	0.74	0.02	3
4 September	0.77	0.04	6	0.78	0.10	13
1 October	0.83	0.09	12	0.74	0.03	4
6 November	0.72	0.08	12	0.73	0.04	6
6 December				0.70	0.18	24

Table 115. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.73	0.04	5
3 June	0.73	0.04	5
1 July	0.72	0.07	10
30 July	0.74	0.07	10
4 September	0.82	0.04	5
1 October	0.69	0.08	12
6 November	0.66	0.16	23
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent N content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 116. Mean proportion[a] of initial total nitrogen mass remaining at different times in 1986, for bulk red maple foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.77	0.04	6	0.79	0.11	14
3 June	0.76	0.03	4	0.79	0.04	5
1 July	0.87	0.11	14	0.83	0.06	7
30 July	0.80	0.08	10	0.80	0.04	5
4 September	0.80	0.11	14	0.85	0.06	8
1 October	0.64	0.06	10	0.83	0.09	12
6 November	0.56	0.11	21	0.70	0.04	7
6 December				0.75	0.08	9

Table 116. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.84	0.11	14	0.83	0.06	8
3 June	0.77	0.04	6	0.83	0.11	13
1 July	0.83	0.06	8	0.87	0.10	13
30 July	0.82	0.15	20	0.80	0.12	16
4 September	0.85	0.05	6	0.86	0.08	10
1 October	0.80	0.20	31	0.80	0.08	11
6 November	0.80	0.14	19	0.76	0.08	10
6 December				0.43	0.14	30

Table 116. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.74	0.05	6
3 June	0.76	0.08	11
1 July	0.92	0.07	8
30 July	0.82	0.09	12
4 September	0.78	0.07	10
1 October	0.73	0.10	14
6 November	0.48	0.27	60
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent N content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 117. Mean proportion[a] of initial total phosphorus mass remaining at different times in 1986, for bulk red pine foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.32	0.02	8	0.33	0.03	10
3 June	0.31	0.02	8	0.35	0.02	6
1 July	0.38	0.08	21	0.37	0.03	8
30 July	0.31	0.02	8	0.35	0.02	7
4 September	0.23	0.03	14	0 30	0.05	16
1 October	0.26	0.05	20	0.29	0.03	10
6 November	0.30	0.06	21	0.34	0.04	12
6 December				0.53	0.07	12

Table 117. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.36	0.04	13	0.34	0.04	12
3 June	0.33	0.08	26	0.34	0.03	10
1 July	0.34	0.03	9	0.36	0.03	8
30 July	0.31	0.03	9	0.33	0.01	4
4 September	0.31	0.03	9	0.33	0.03	10
1 October	0.27	0.02	10	0.30	0.03	11
6 November	0.26	0.05	20	0.30	0.07	24
6 December				0.59	0.04	7

Table 117. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.30	0.01	5
3 June	0.34	0.03	11
1 July	0.36	0.02	7
30 July	0.29	0.03	9
4 September	0.27	0.04	14
1 October	0.24	0.04	19
6 November	0.28	0.02	7
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent P content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 118. Mean proportion[a] of initial total phosphorus mass remaining at different times in 1986, for bulk red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.41	0.03	9	0.42	0.03	8
3 June	0.45	0.05	13	0.46	0.04	9
1 July	0.39	0.01	2	0.46	0.04	10
30 July	0.41	0.03	9	0.47	0.08	18
4 September	0.37	0.04	11	0.45	0.05	12
1 October	0.39	0.07	19	0.54	0.06	11
6 November	0.33	0.04	14	0.51	0.06	12
6 December				0.31	0.16	46

Table 118. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.34	0.04	13	0.33	0.02	8
3 June	0.44	0.02	6	0.35	0.02	5
1 July	0.38	0.03	9	0.42	0.05	13
30 July	0.40	0.04	10	0.38	0.01	4
4 September	0.43	0.03	70	0.42	0.05	13
1 October	0.46	0.06	14	0.46	0.05	10
6 November	0.40	0.05	12	0.52	0.06	12
6 December				0.48	0.09	17

Table 118. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.37	0.02	6
3 June	0.44	0.04	9
1 July	0.37	0.07	20
30 July	0.38	0.04	12
4 September	0.42	0.03	8
1 October	0.33	0.05	15
6 November	0.29	0.07	21
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent P content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 119. Mean proportion[a] of initial total phosphorus mass remaining at different times in 1986, for bulk red maple foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.54	0.05	9	0.60	0.09	15
3 June	0.55	0.04	9	0.60	0.02	4
1 July	0.55	0.06	12	0.59	0.06	10
30 July	0.49	0.05	10	0.56	0.04	7
4 September	0.46	0.07	16	0.61	0.07	11
1 October	0.36	0.06	17	0.63	0.08	13
6 November	0.30	0.07	24	0.48	0.05	11
6 December				0.47	0.05	11

Table 119. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.57	0.09	16	0.59	0.04	7
3 June	0.61	0.04	6	0.65	0.06	10
1 July	0.53	0.05	9	0.64	0.09	14
30 July	0.54	0.09	18	0.61	0.08	13
4 September	0.58	0.04	7	0.62	0.05	8
1 October	0.50	0.11	25	0.59	0.06	10
6 November	0.48	0.10	22	0.56	0.06	11
6 December				0.33	0.07	20

Table 119. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.51	0.03	6
3 June	0.51	0.06	11
1 July	0.60	0.06	10
30 July	0.53	0.08	17
4 September	0.42	0.05	14
1 October	0.39	0.06	15
6 November	0.29	0.17	61
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent P content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 120. Mean proportion[a] of initial total potassium mass remaining at different times in 1986, for bulk red pine foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.17	0.02	13	0.19	0.03	17
3 June	0.23	0.03	13	0.29	0.04	14
1 July	0.25	0.13	53	0.25	0.02	10
30 July	0.16	0.03	17	0.22	0.03	12
4 September	0.11	0.02	23	0 13	0.01	12
1 October	0.11	0.02	20	0.19	0.02	12
6 November	0.14	0.07	53	0.19	0.05	26
6 December				0.20	0.04	20

Table 120. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.20	0.07	37	0.29	0.03	11
3 June	0.19	0.02	9	0.21	0.03	13
1 July	0.21	0.06	32	0.23	0.03	15
30 July	0.20	0.07	38	0.20	0.02	10
4 September	0.14	0.03	23	0.14	0.02	17
1 October	0.14	0.06	49	0.17	0.03	17
6 November	0.14	0.04	29	0.24	0.06	26
6 December				0.22	0.04	17

Table 120. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.17	0.03	18
3 June	0.27	0.05	19
1 July	0.18	0.02	13
30 July	0.14	0.02	13
4 September	0.13	0.06	53
1 October	0.08	0.02	31
6 November	0.11	0.03	21
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent K content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 121. Mean proportion[a] of initial total potassium mass remaining at different times in 1986, for bulk red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.26	0.03	14	0.29	0.05	17
3 June	0.23	0.02	10	0.33	0.06	18
1 July	0.25	0.04	16	0.30	0.04	13
30 July	0.27	0.05	18	0.28	0.03	10
4 September	0.19	0.01	6	0.26	0.13	52
1 October	0.28	0.06	24	0.43	0.05	11
6 November	0.23	0.04	19	0.40	0.06	17
6 December				0.36	0.07	19

Table 121. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.24	0.03	12	0.23	0.04	18
3 June	0.28	0.06	23	0.25	0.02	7
1 July	0.30	0.06	22	0.30	0.05	16
30 July	0.27	0.06	22	0.28	0.02	7
4 September	0.34	0.09	28	0.30	0.03	11
1 October	0.33	0.03	9	0.40	0.05	12
6 November	0.26	0.07	26	0.38	0.06	18
6 December				0.41	0.04	10

Table 121. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.26	0.03	13
3 June	0.24	0.02	8
1 July	0.25	0.02	8
30 July	0.25	0.03	12
4 September	0.23	0.03	14
1 October	0.21	0.03	16
6 November	0.21	0.05	22
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent K content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 122. Mean proportion[a] of initial total potassium mass remaining at different times in 1986, for bulk red maple foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.32	0.02	8	0.44	0.06	14
3 June	0.32	0.05	16	0.37	0.02	5
1 July	0.29	0.05	17	0.42	0.06	16
30 July	0.20	0.03	15	0.25	0.02	8
4 September	0.17	0.05	29	0.26	0.05	19
1 October	0.18	0.05	30	0.32	0.03	9
6 November	0.12	0.03	27	0.28	0.04	14
6 December				0.32	0.08	24

Table 122. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.37	0.06	18	0.39	0.05	13
3 June	0.33	0.03	9	0.33	0.02	8
1 July	0.31	0.05	15	0.33	0.05	15
30 July	0.23	0.01	6	0.27	0.02	7
4 September	0.25	0.08	33	0.25	0.03	11
1 October	0.25	0.06	29	0.34	0.05	16
6 November	0.26	0.06	24	0.31	0.06	20
6 December				0.38	0.05	11

Table 122. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.34	0.05	15
3 June	0.34	0.09	27
1 July	0.27	0.05	20
30 July	0.23	0.03	16
4 September	0.18	0.04	25
1 October	0.22	0.09	43
6 November	0.13	0.08	61
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent K content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.

b/ standard deviation

c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 123. Mean proportion[a] of initial total calcium mass remaining at different times in 1986, for bulk red pine foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.32	0.02	7	0.31	0.03	10
3 June	0.39	0.02	7	0.40	0.04	10
1 July	0.40	0.02	6	0.41	0.04	10
30 July	0.37	0.02	5	0.38	0.03	8
4 September	0.33	0.04	12	0 37	0.02	7
1 October	0.35	0.04	13	0.39	0.02	6
6 November	0.31	0.04	13	0.32	0.03	10
6 December				0.37	0.04	10

Table 123. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.34	0.09	28	0.45	0.07	16
3 June	0.35	0.03	9	0.38	0.02	7
1 July	0.39	0.04	10	0.40	0.04	11
30 July	0.38	0.02	6	0.37	0.02	6
4 September	0.33	0.01	4	0.37	0.02	6
1 October	0.40	0.05	13	0.39	0.03	7
6 November	0.33	0.02	7	0.36	0.04	11
6 December				0.38	0.02	6

Table 123. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.36	0.03	10
3 June	0.44	0.03	7
1 July	0.45	0.06	13
30 July	0.35	0.04	11
4 September	0.36	0.03	9
1 October	0.38	0.03	8
6 November	0.33	0.03	9
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent Ca content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.

b/ standard deviation

c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean ($n = 6$)

Table 124. Mean proportion[a] of initial total calcium mass remaining at different times in 1986, for bulk red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.88	0.07	8	1.01	0.04	4
3 June	1.04	0.04	4	1.03	0.06	6
1 July	1.00	0.06	6	0.95	0.03	4
30 July	0.89	0.05	6	0.96	0.04	5
4 September	0.89	0.04	5	1.00	0.05	5
1 October	0.87	0.10	12	0.98	0.07	8
6 November	0.79	0.11	14	0.90	0.03	3
6 December				0.85	0.11	12

Table 124. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	1.00	0.05	5	0.95	0.05	5
3 June	0.99	0.04	5	1.04	0.06	6
1 July	0.98	0.04	4	1.01	0.03	4
30 July	0.95	0.04	5	1.01	0.05	6
4 September	0.99	0.07	7	0.98	0.06	6
1 October	0.94	0.06	6	0.95	0.06	7
6 November	0.82	0.12	15	0.85	0.03	4
6 December				0.86	0.05	5

Table 124. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.90	0.05	6
3 June	1.02	0.03	3
1 July	1.00	0.03	3
30 July	0.89	0.05	6
4 September	0.91	0.05	5
1 October	0.91	0.07	9
6 November	0.72	0.18	23
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent Ca content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 125. Mean proportion[a] of initial total calcium mass remaining at different times in 1986, for bulk red maple foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.87	0.10	12	0.94	0.06	6
3 June	0.92	0.10	12	0.94	0.03	4
1 July	0.83	0.08	10	0.92	0.07	8
30 July	0.72	0.04	5	0.85	0.06	7
4 September	0.64	0.07	12	0.88	0.04	5
1 October	0.47	0.03	7	0.71	0.12	17
6 November	0.45	0.12	27	0.67	0.05	7
6 December				0.73	0.08	10

Table 125. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.83	0.06	7	0.88	0.08	10
3 June	0.87	0.09	11	0.95	0.11	12
1 July	0.80	0.04	5	0.91	0.11	13
30 July	0.71	0.04	7	0.77	0.09	13
4 September	0.82	0.10	13	0.87	0.11	13
1 October	0.51	0.08	18	0.68	0.05	7
6 November	0.66	0.12	19	0.70	0.05	7
6 December				0.74	0.05	7

Table 125. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.87	0.06	7
3 June	0.79	0.06	8
1 July	0.86	0.06	8
30 July	0.77	0.04	6
4 September	0.69	0.06	9
1 October	0.61	0.07	11
6 November	0.39	0.22	60
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent Ca content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 126. Mean proportion[a] of initial total magnesium mass remaining at different times in 1986, for bulk red pine foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.58	0.06	11	0.61	0.03	6
3 June	0.53	0.06	13	0.63	0.07	11
1 July	0.42	0.05	12	0.52	0.04	8
30 July	0.43	0.05	13	0.47	0.04	9
4 September	0.28	0.01	5	0 36	0.04	12
1 October	0.26	0.04	15	0.34	0.03	10
6 November	0.29	0.09	32	0.31	0.05	16
6 December				0.31	0.08	23

Table 126. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.56	0.06	11	0.65	0.08	12
3 June	0.45	0.04	10	0.53	0.03	5
1 July	0.41	0.02	6	0.47	0.08	17
30 July	0.39	0.06	15	0.43	0.03	7
4 September	0.31	0.05	18	0.40	0.04	11
1 October	0.28	0.06	21	0.34	0.06	18
6 November	0.27	0.07	28	0.31	0.04	15
6 December				0.30	0.02	6

Table 126. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.60	0.05	9
3 June	0.60	0.07	11
1 July	0.50	0.05	10
30 July	0.38	0.06	15
4 September	0.30	0.06	20
1 October	0.27	0.08	30
6 November	0.23	0.04	17
6 December			

a/ Proportion ($X=^{M}1/M_0$), where M_0 and M_1 are the percent Mg content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 127. Mean proportion[a] of initial total magnesium mass remaining at different times in 1986, for bulk red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.96	0.13	14	0.85	0.03	4
3 June	0.76	0.05	6	0.86	0.04	5
1 July	0.72	0.08	12	0.82	0.04	5
30 July	0.59	0.05	10	0.66	0.04	6
4 September	0.49	0.04	8	0.65	0.03	5
1 October	0.46	0.09	21	0.61	0.05	8
6 November	0.43	0.08	19	0.57	0.11	20
6 December				0.51	0.16	30

Table 127. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.80	0.03	4	0.82	0.05	6
3 June	0.80	0.04	5	0.89	0.03	4
1 July	0.74	0.06	8	0.80	0.04	5
30 July	0.59	0.07	12	0.69	0.04	6
4 September	0.67	0.21	33	0.63	0.03	5
1 October	0.51	0.04	8	0.54	0.04	7
6 November	0.46	0.06	14	0.52	0.05	10
6 December				0.52	0.04	8

Table 127. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	1.00	0.06	7
3 June	0.78	0.03	4
1 July	0.79	0.03	4
30 July	0.58	0.04	7
4 September	0.53	0.05	10
1 October	0.43	0.04	9
6 November	0.35	0.08	21
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent Mg content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 128. Mean proportion[a] of initial total magnesium mass remaining at different times in 1986, for bulk red maple foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.83	0.04	5	0.95	0.03	3
3 June	0.68	0.10	15	0.74	0.05	7
1 July	0.50	0.04	9	0.66	0.08	13
30 July	0.38	0.04	10	0.53	0.04	7
4 September	0.30	0.06	22	0.58	0.10	19
1 October	0.25	0.08	32	0.50	0.09	18
6 November	0.23	0.11	48	0.47	0.05	11
6 December				0.53	0.10	18

Table 128. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.91	0.04	5	0.93	0.05	5
3 June	0.63	0.06	10	0.71	0.06	9
1 July	0.49	0.06	13	0.61	0.09	15
30 July	0.43	0.05	11	0.52	0.04	9
4 September	0.49	0.14	30	0.57	0.09	16
1 October	0.36	0.09	28	0.50	0.05	11
6 November	0.41	0.09	23	0.49	0.05	10
6 December				0.50	0.05	9

Table 128. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.83	0.07	9
3 June	0.63	0.05	8
1 July	0.61	0.02	4
30 July	0.44	0.05	12
4 September	0.30	0.06	19
1 October	0.29	0.05	18
6 November	0.21	0.15	74
6 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent Mg content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 129. Ash mass as mean percent of dry matter mass remaining at different times in 1986, for bulk red pine foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.99	0.16	16	1.04	0.29	30
3 June	1.32	0.34	27	1.04	0.23	23
1 July	1.37	0.21	16	1.23	0.15	13
30 July	1.18	0.33	29	1.23	0.23	20
4 September	1.13	0.31	29	1 37	0.60	46
1 October	1.56	1.32	89	1.46	0.60	43
6 November	1.27	0.47	38	1.27	0.30	24
6 December				1.17	0.38	30

Table 129. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.94	0.23	26	1.18	0.42	37
3 June	0.90	0.28	33	1.18	0.38	33
1 July	1.32	0.29	23	1.27	0.24	20
30 July	1.27	0.24	20	1.08	0.28	27
4 September	1.18	0.45	40	1.42	0.31	23
1 October	1.32	0.53	42	1.42	0.36	27
6 November	1.13	0.31	29	1.27	0.30	24
6 December				1.50	0.21	13

Table 129. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	1.08	0.21	21
3 June	1.32	0.29	23
1 July	1.13	0.36	33
30 July	1.23	0.15	13
4 September	1.23	0.15	13
1 October	1.13	0.18	17
6 November	1.21	0.27	21
6 December			

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 130. Ash mass as mean percent of dry matter mass remaining at different times in 1986, for bulk red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	0.99	0.12	13	1.01	0.08	8
3 June	1.07	0.13	13	1.11	0.09	9
1 July	1.15	0.19	17	1.18	0.19	17
30 July	1.13	0.16	15	1.13	0.20	18
4 September	1.11	0.24	23	1.43	0.19	14
1 October	1.32	0.15	12	1.66	0.31	20
6 November	1.30	0.28	23	1.57	0.28	19
6 December				1.57	0.20	12

Table 130. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	1.07	0.07	7	1.09	0.13	13
3 June	1.03	0.05	5	1.15	0.09	9
1 July	1.09	0.15	15	1.13	0.20	18
30 July	1.03	0.12	13	1.22	0.13	11
4 September	1.36	0.12	10	1.28	0.17	14
1 October	1.47	0.25	18	1.39	0.20	15
6 November	1.34	0.15	12	1.39	0.15	12
6 December				1.40	0.16	10

Table 130. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	1.01	0.08	8
3 June	1.07	0.11	10
1 July	1.01	0.14	14
30 July	1.13	0.21	20
4 September	1.32	0.28	23
1 October	1.30	0.17	14
6 November	1.26	0.10	8
6 December			

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,5}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

Table 131. Ash mass as mean percent of dry matter mass remaining at different times in 1986, for bulk red maple foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Unit					
	Plantation			Hardwood Stand		
	Mean	S.D.[a]	%[b]	Mean	S.D.	%
7 May	1.06	0.13	13	1.08	0.13	12
3 June	1.21	0.19	17	1.06	0.09	9
1 July	0.96	0.22	24	1.09	0.04	4
30 July	1.09	0.16	16	1.12	0.09	9
4 September	1.23	0.20	17	1.18	0.12	11
1 October	1.20	0.15	13	1.33	0.14	11
6 November	1.17	0.32	28	1.39	0.46	35
6 December				1.28	0.12	9

Table 131. (cont)

Sampling Date	Control Unit					
	Plantation			Hardwood Stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.97	0.07	7	1.06	0.14	14
3 June	0.93	0.07	8	0.99	0.16	17
1 July	0.99	0.08	9	1.05	0.14	14
30 July	1.06	0.16	16	1.05	0.09	9
4 September	1.23	0.11	9	1.11	0.18	17
1 October	1.26	0.06	6	1.20	0.09	8
6 November	1.27	0.13	11	1.32	0.12	10
6 December				1.22	0.14	10

Table 131. (cont)

Sampling Date	Ground Unit		
	Plantation		
	Mean	S.D.	%
7 May	0.99	0.06	6
3 June	1.02	0.15	15
1 July	1.14	0.12	11
30 July	1.18	0.13	12
4 September	1.30	0.08	6
1 October	1.23	0.05	4
6 November	1.20	0.23	20
6 December			

a/ standard deviation
b/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$ * S.E./Mean, and expressed as a percentage of the sample mean (n = 6)

FIGURE 49. **BULK FOLIAR LITTER SAMPLES, GROUND PLANTATION**

PROPORTION OF INITIAL NITROGEN MASS REMAINING (1985-1986)

Nitrogen mass changes in bulk samples of freshly fallen foliar litter disbursed on the Ground Plantation subunit on 15 December, 1985, expressed as the proportion of initial nitrogen mass remaining at intervals during the first year of decomposition.

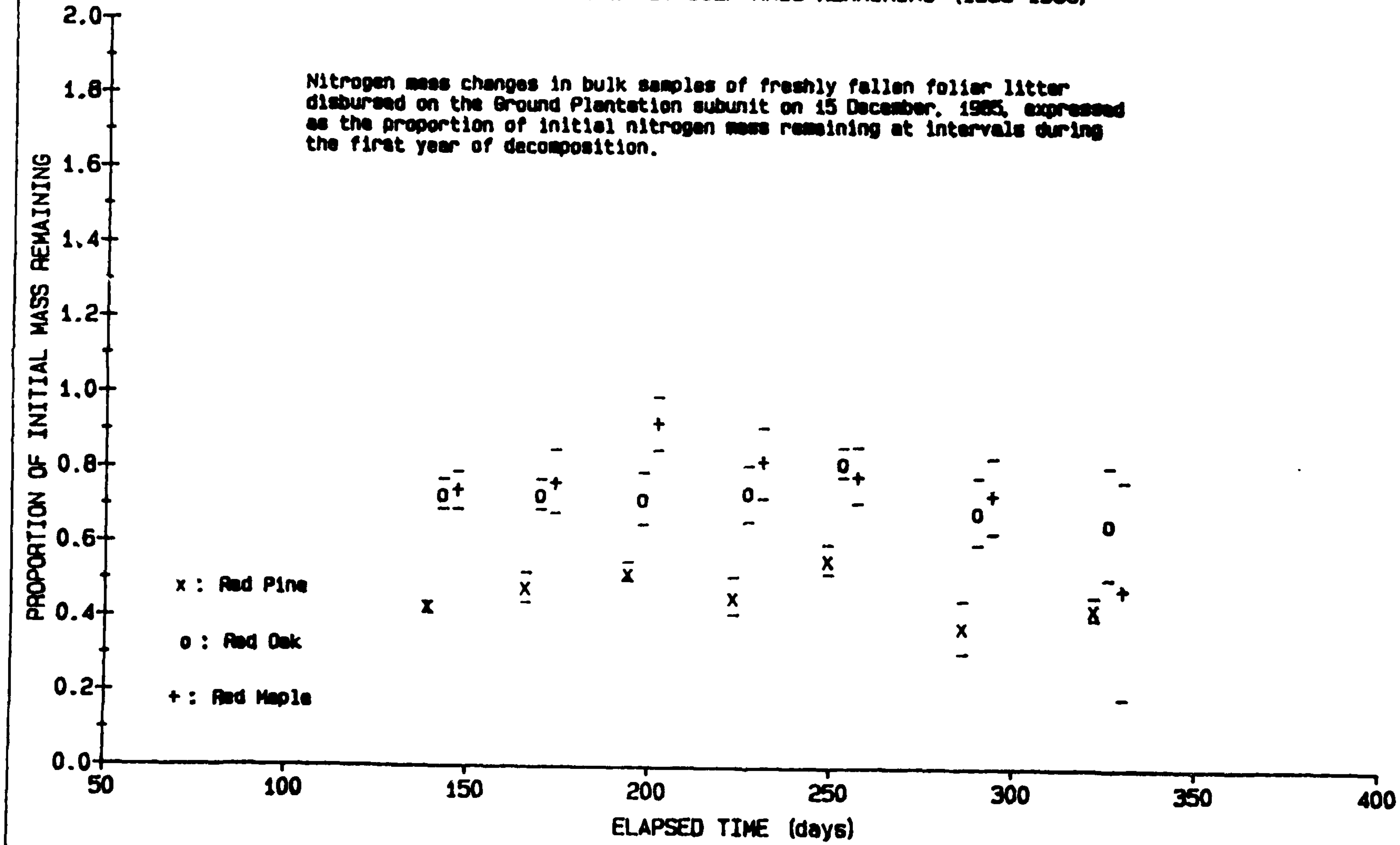
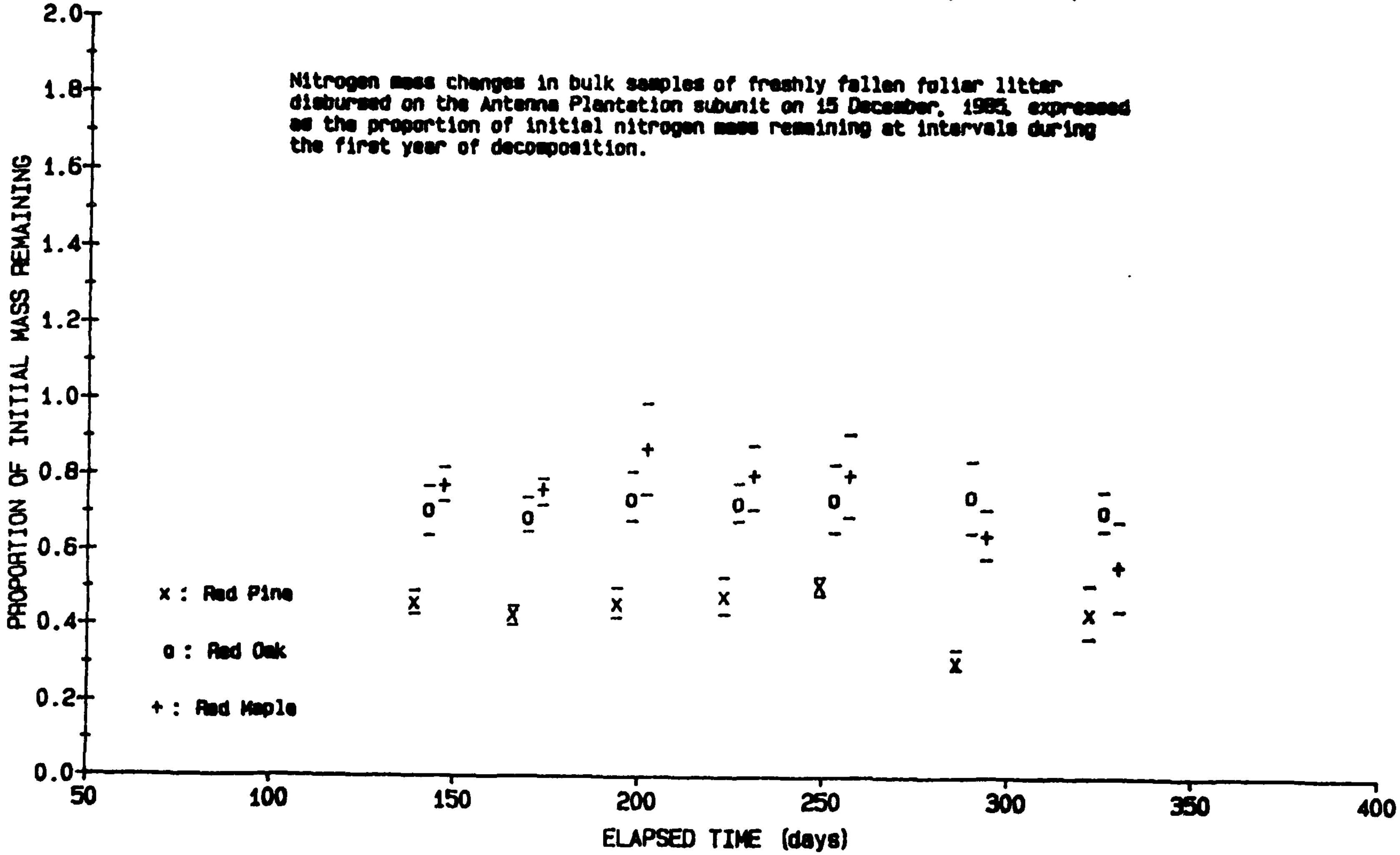


FIGURE 50.

BULK FOLIAR LITTER SAMPLES, ANTENNA PLANTATION

PROPORTION OF INITIAL NITROGEN MASS REMAINING (1985-1986)



Nitrogen mass changes in bulk samples of freshly fallen foliar litter disbursed on the Antenna Plantation subunit on 15 December, 1985, expressed as the proportion of initial nitrogen mass remaining at intervals during the first year of decomposition.

FIGURE 51. **BULK FOLIAR LITTER SAMPLES, CONTROL PLANTATION**

PROPORTION OF INITIAL NITROGEN MASS REMAINING (1985-1986)

Nitrogen mass changes in bulk samples of freshly fallen foliar litter disbursed on the Control Plantation subunit on 15 December, 1985, expressed as the proportion of initial nitrogen mass remaining at intervals during the first year of decomposition.

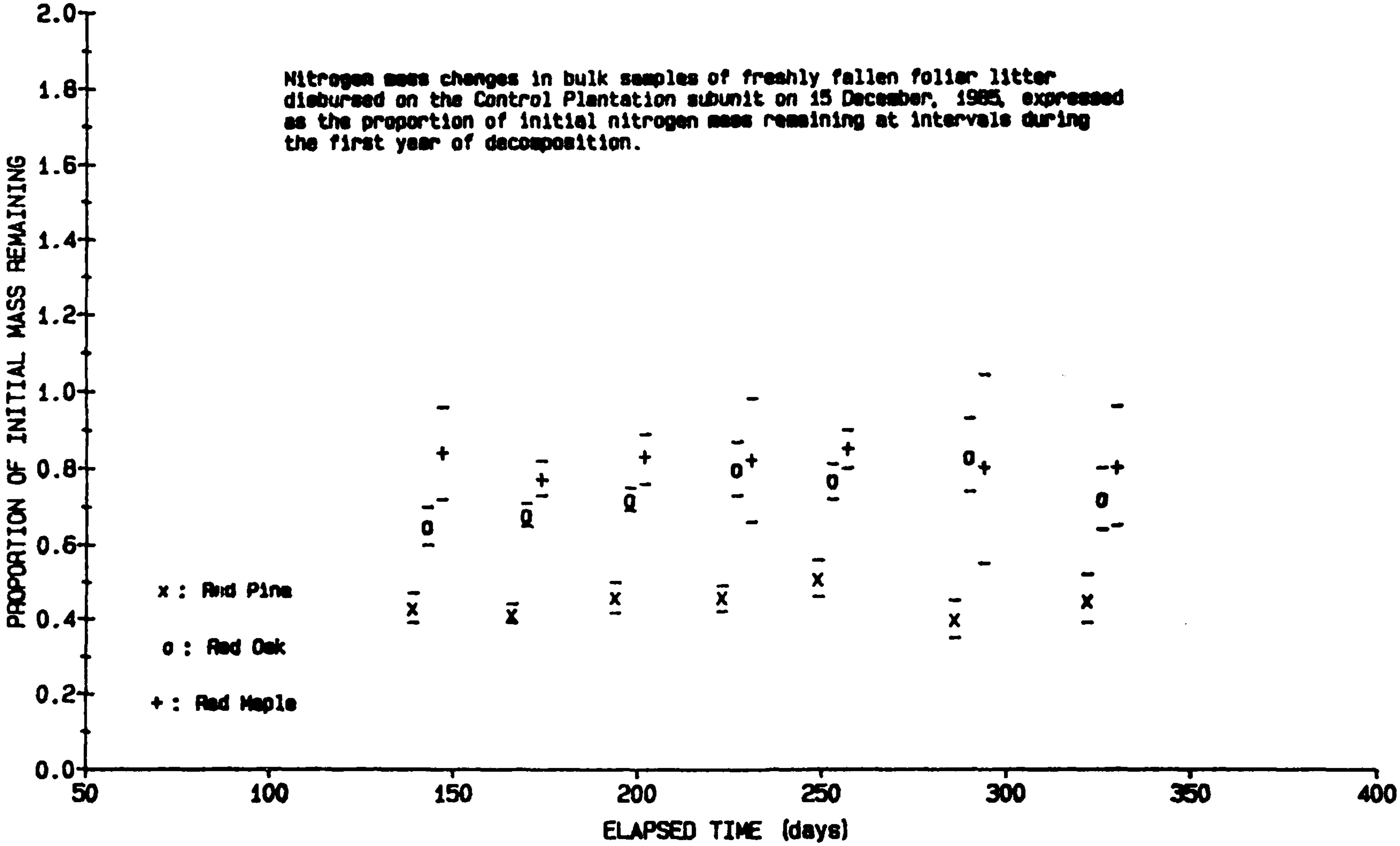


FIGURE 52. **BULK FOLIAR LITTER SAMPLES, ANTENNA HARDWOOD STAND**

PROPORTION OF INITIAL NITROGEN MASS REMAINING (1985–1986)

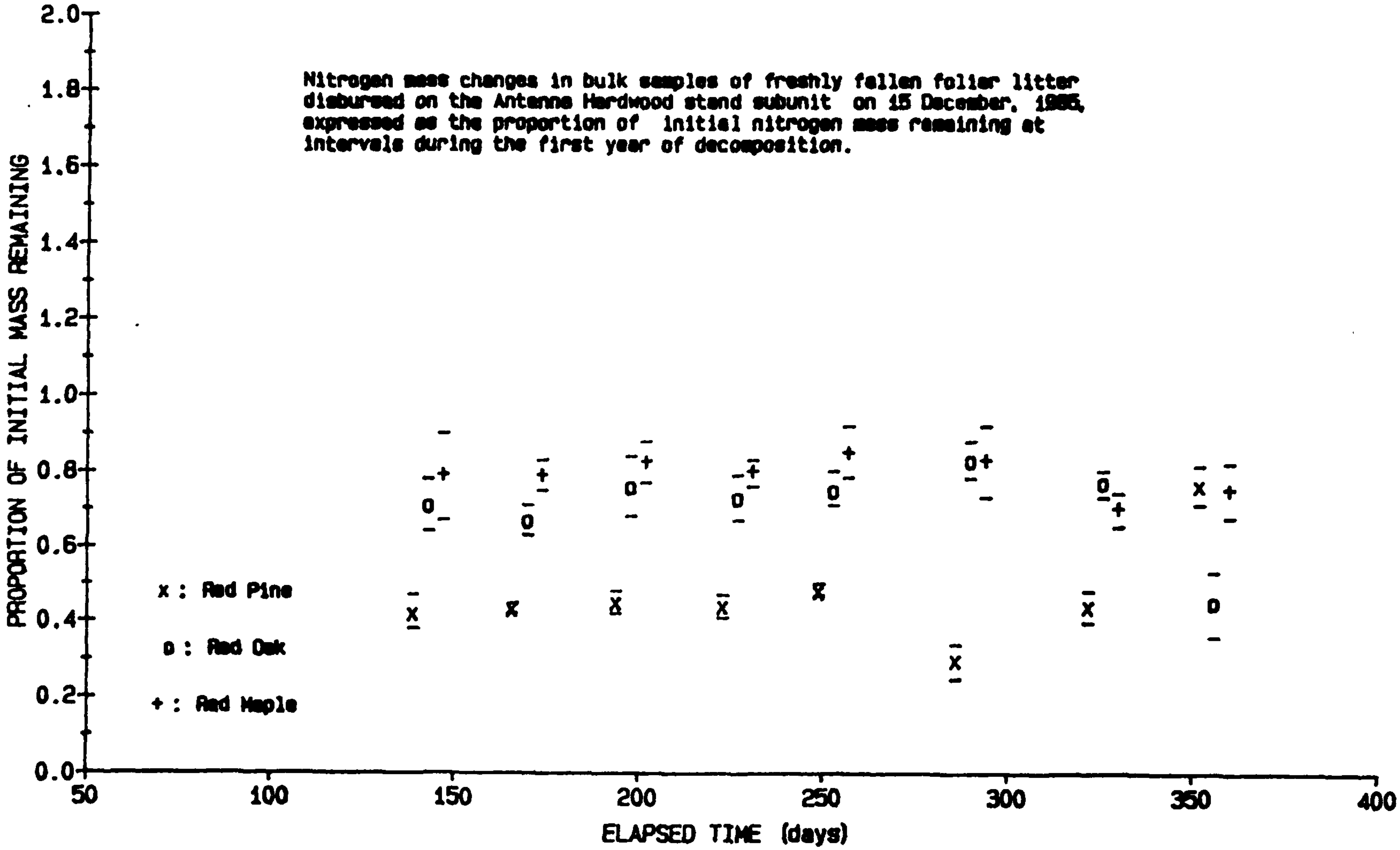


FIGURE 53. **BULK FOLIAR LITTER SAMPLES, CONTROL HARDWOOD STAND**

PROPORTION OF INITIAL NITROGEN MASS REMAINING (1985-1986)

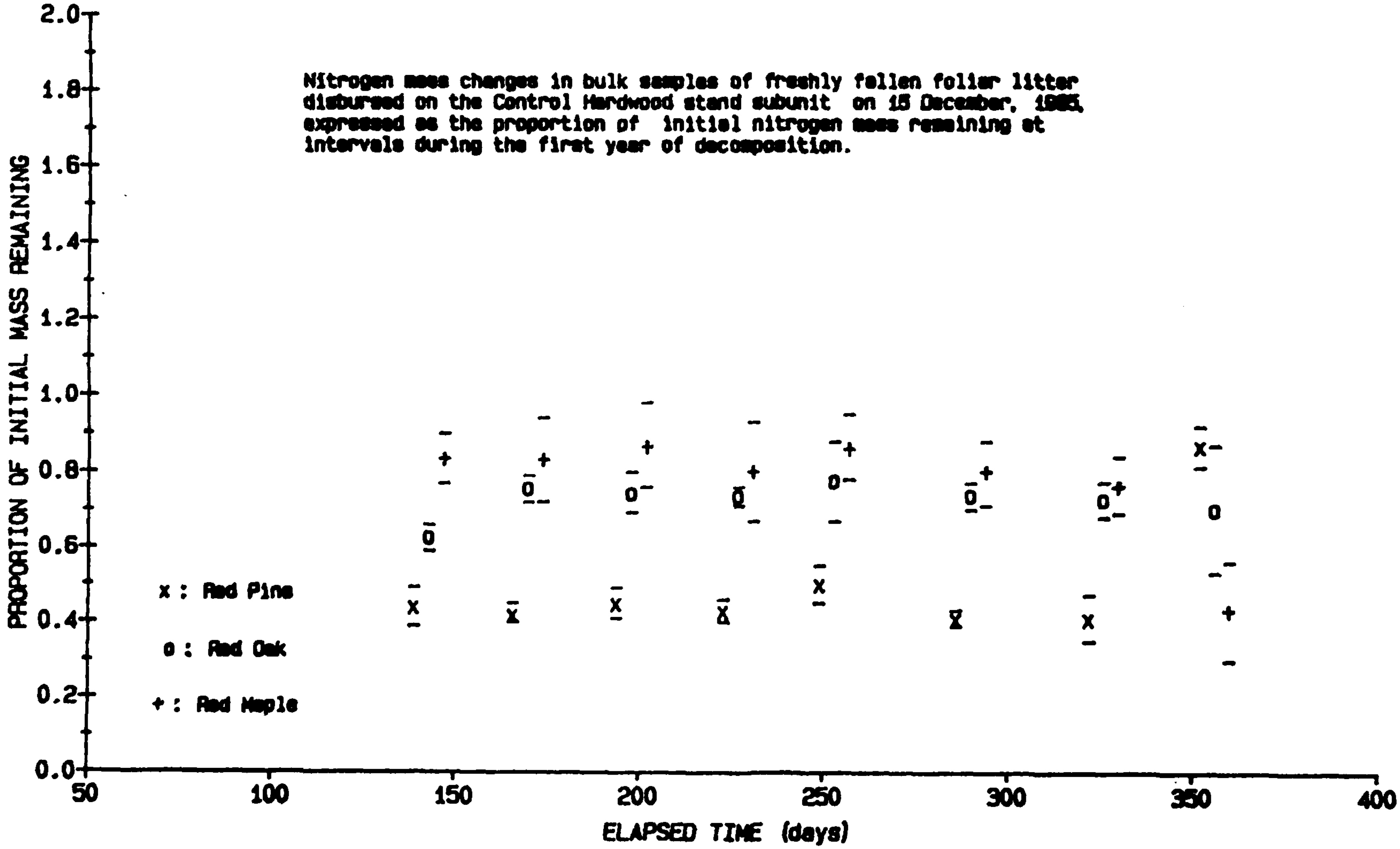


FIGURE 54.

BULK FOLIAR LITTER SAMPLES, GROUND PLANTATION

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1985-1986)

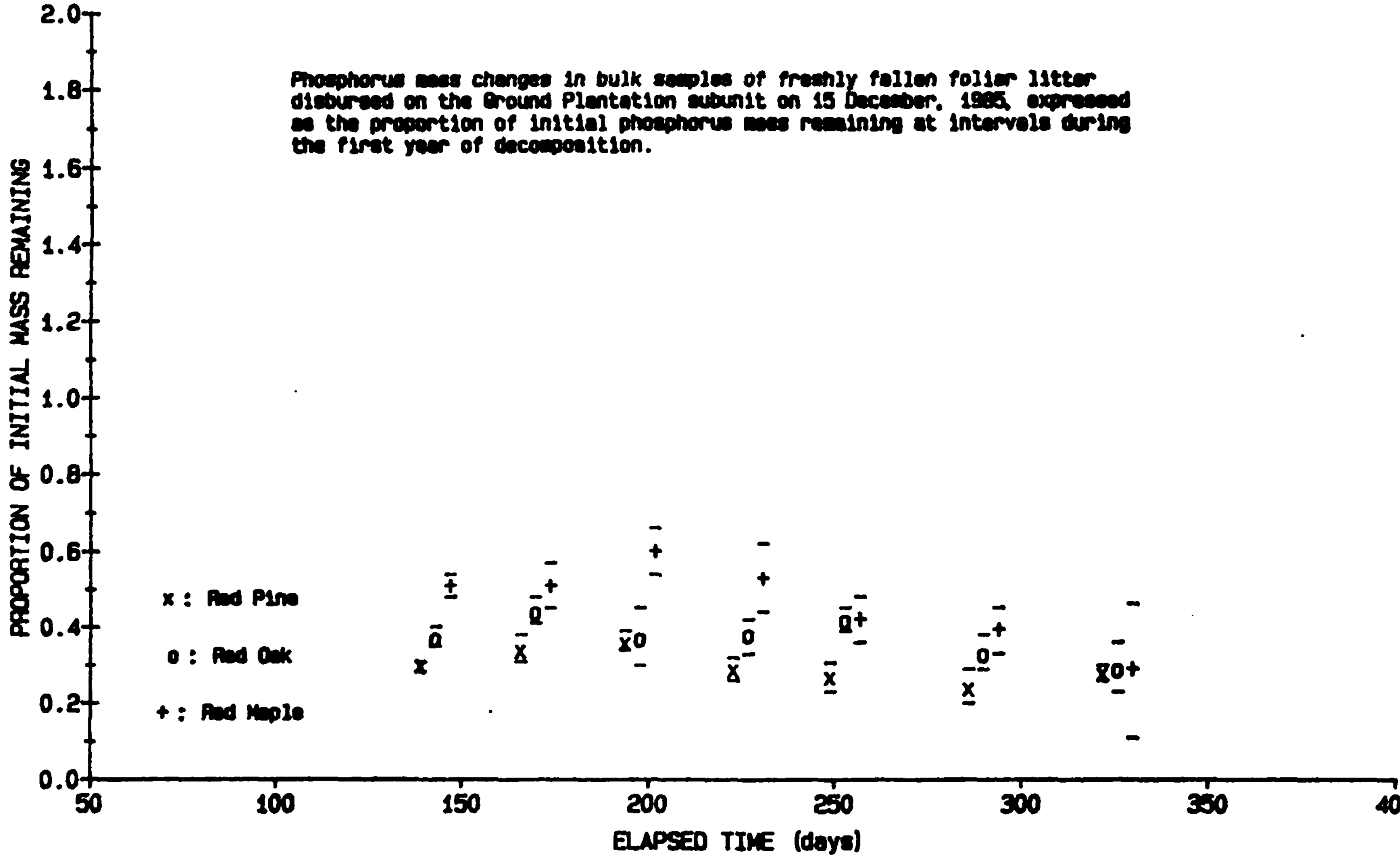


FIGURE 55. **BULK FOLIAR LITTER SAMPLES, ANTENNA PLANTATION**

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1985-1986)

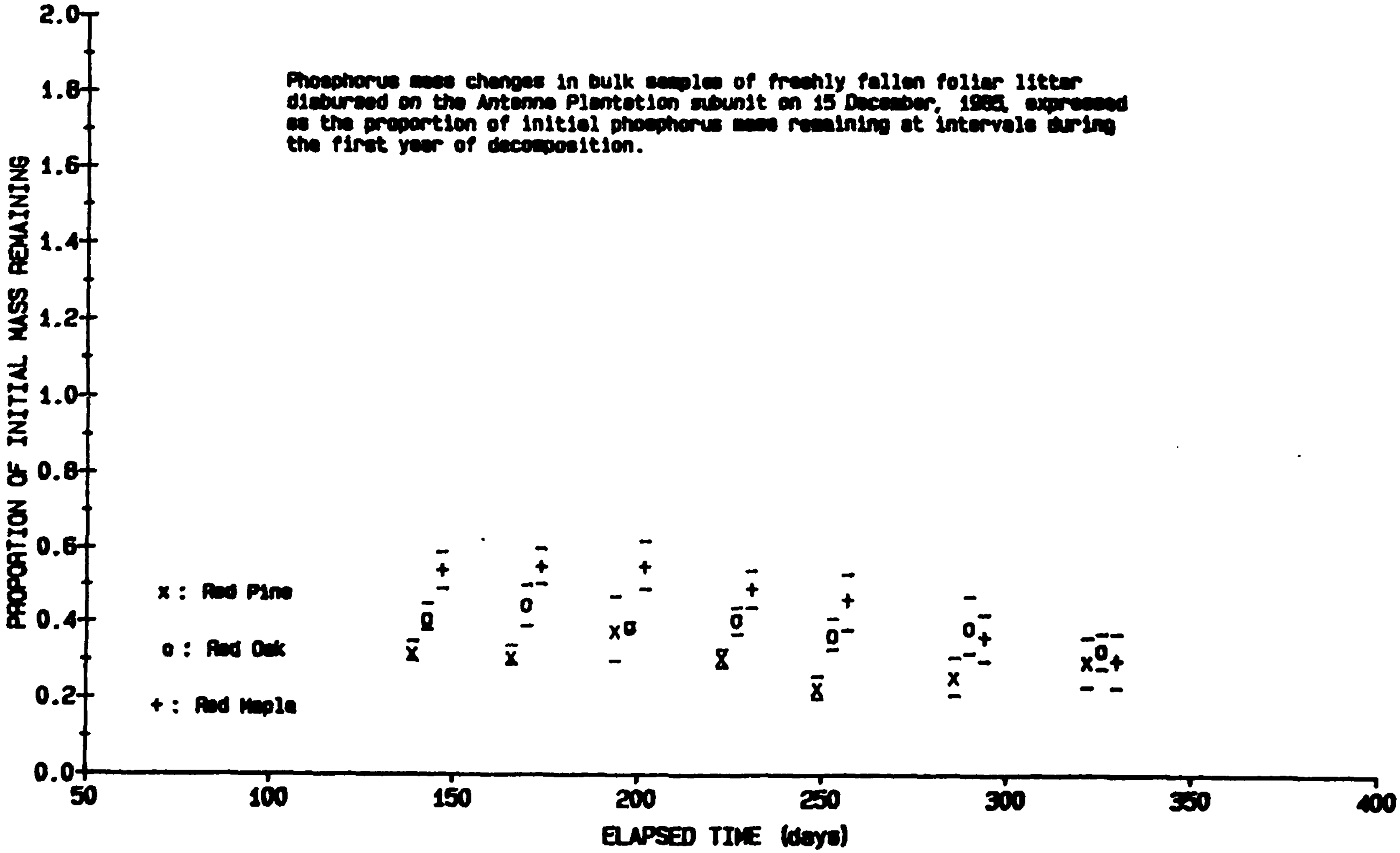


FIGURE 56.

BULK FOLIAR LITTER SAMPLES, CONTROL PLANTATION

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1985-1986)

Phosphorus mass changes in bulk samples of freshly fallen foliar litter disbursed on the Control Plantation subunit on 15 December, 1985, expressed as the proportion of initial phosphorus mass remaining at intervals during the first year of decomposition.

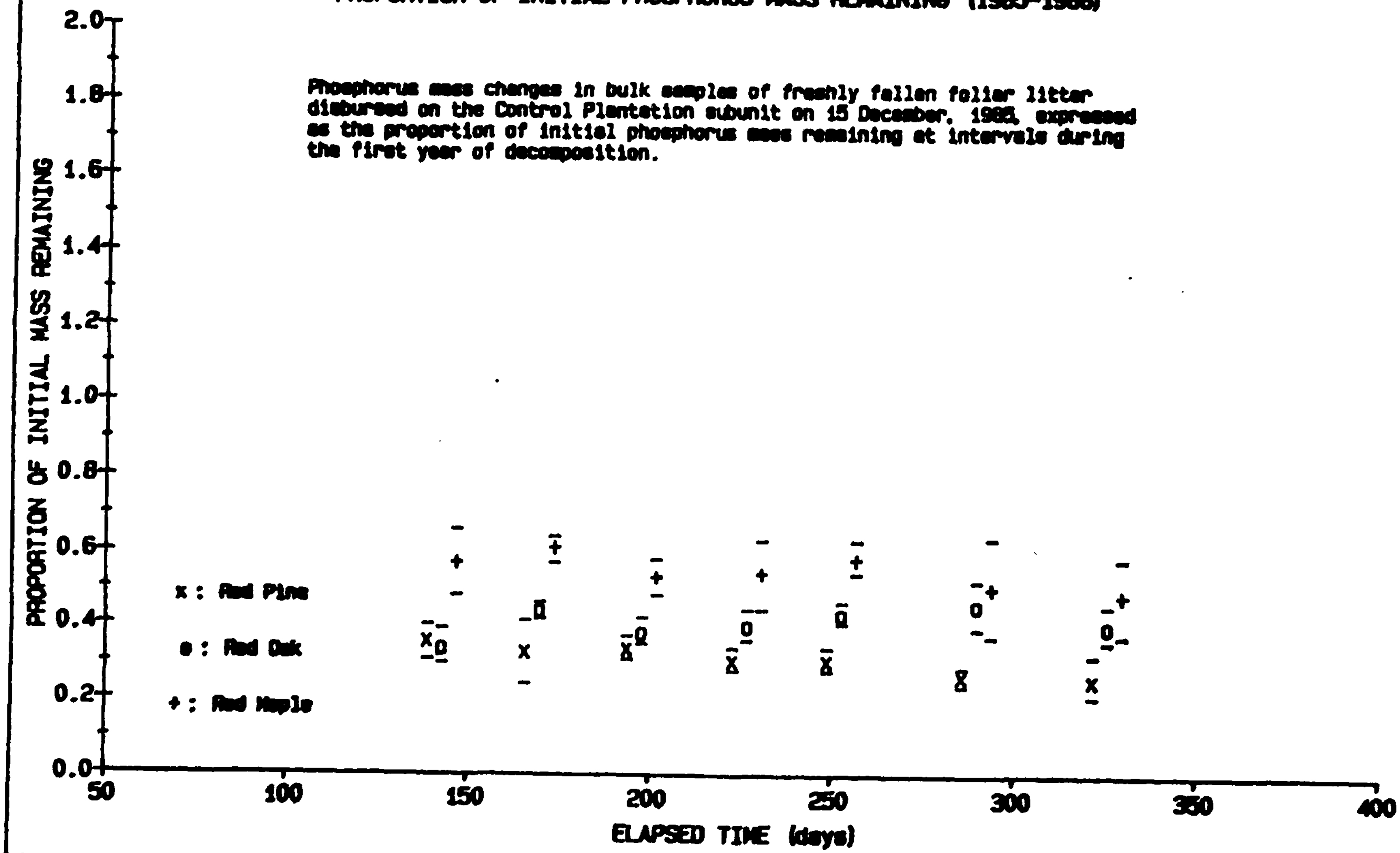


FIGURE 57. BULK FOLIAR LITTER SAMPLES, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1985-1986)

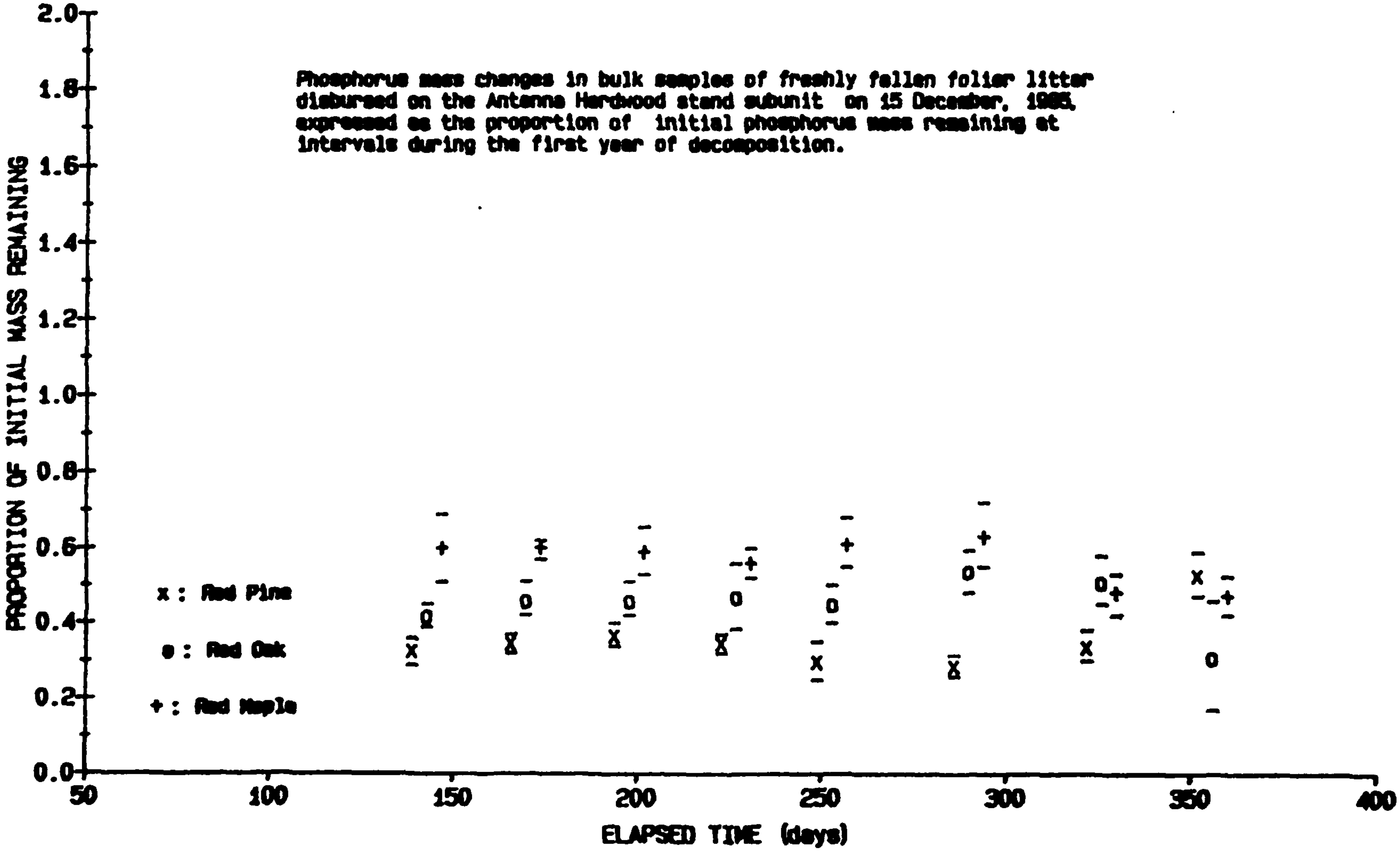


FIGURE 58. **BULK FOLIAR LITTER SAMPLES, CONTROL HARDWOOD STAND**

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1985-1986)

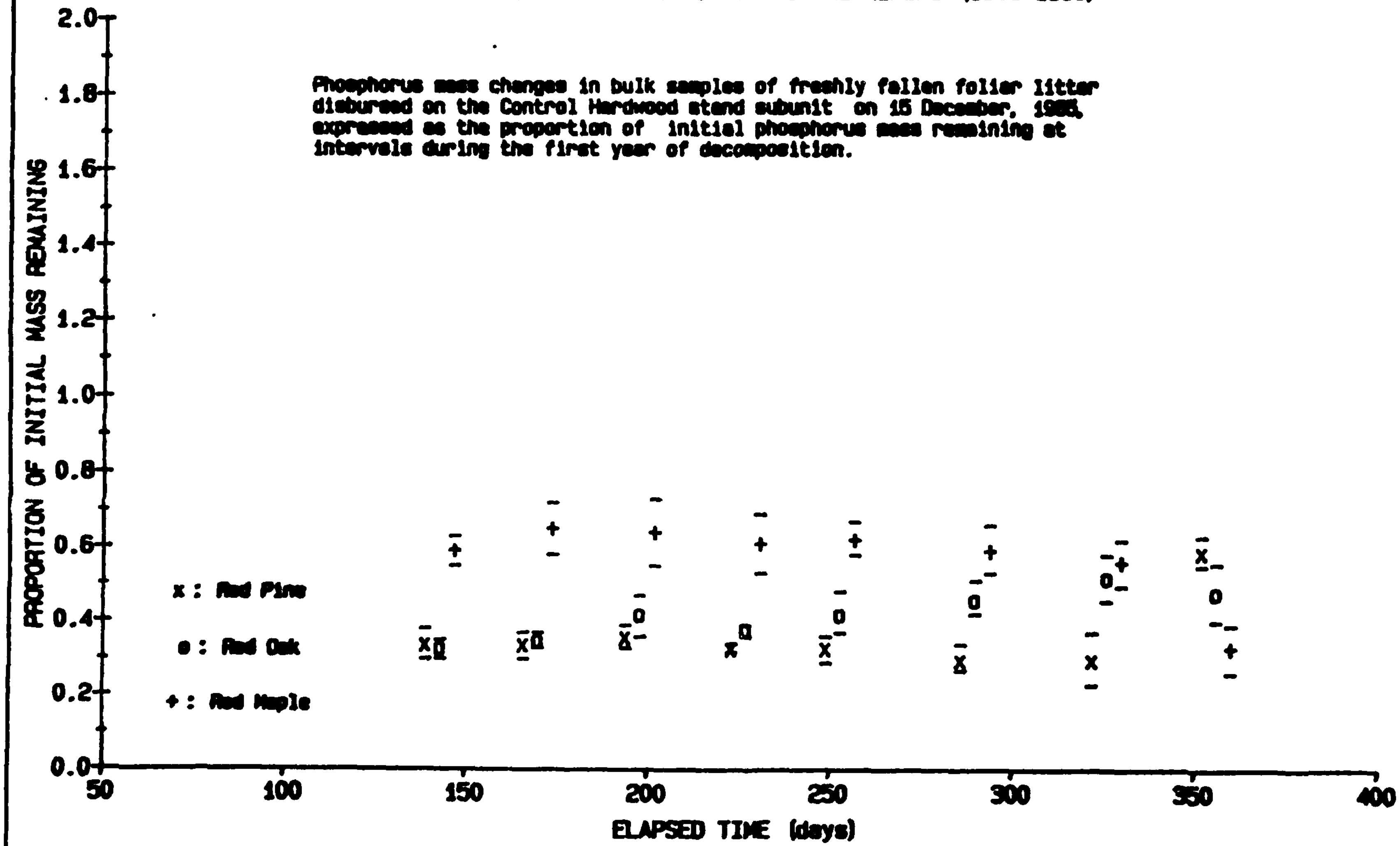


FIGURE 59.

BULK FOLIAR LITTER SAMPLES, GROUND PLANTATION

PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1985-1986)

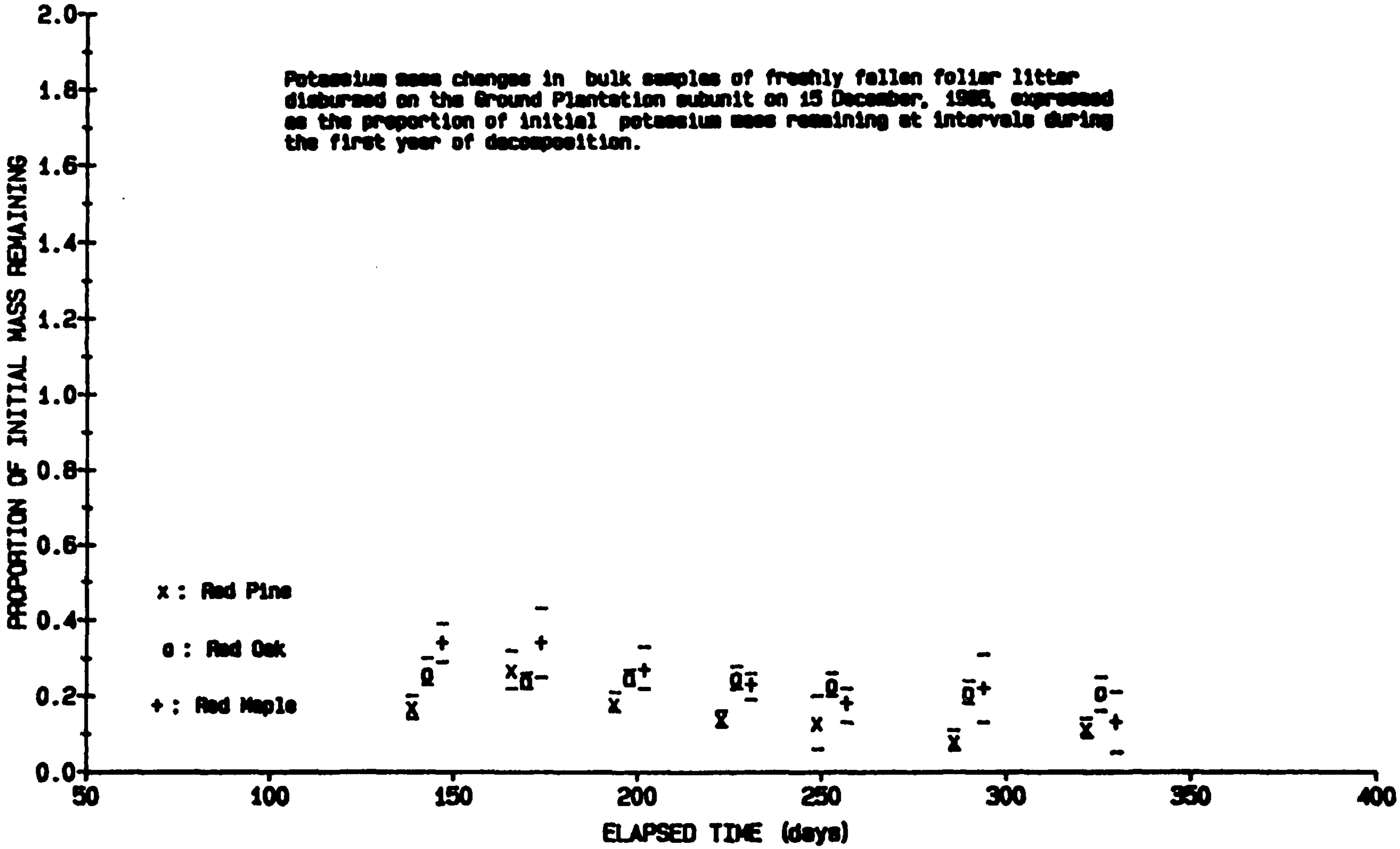
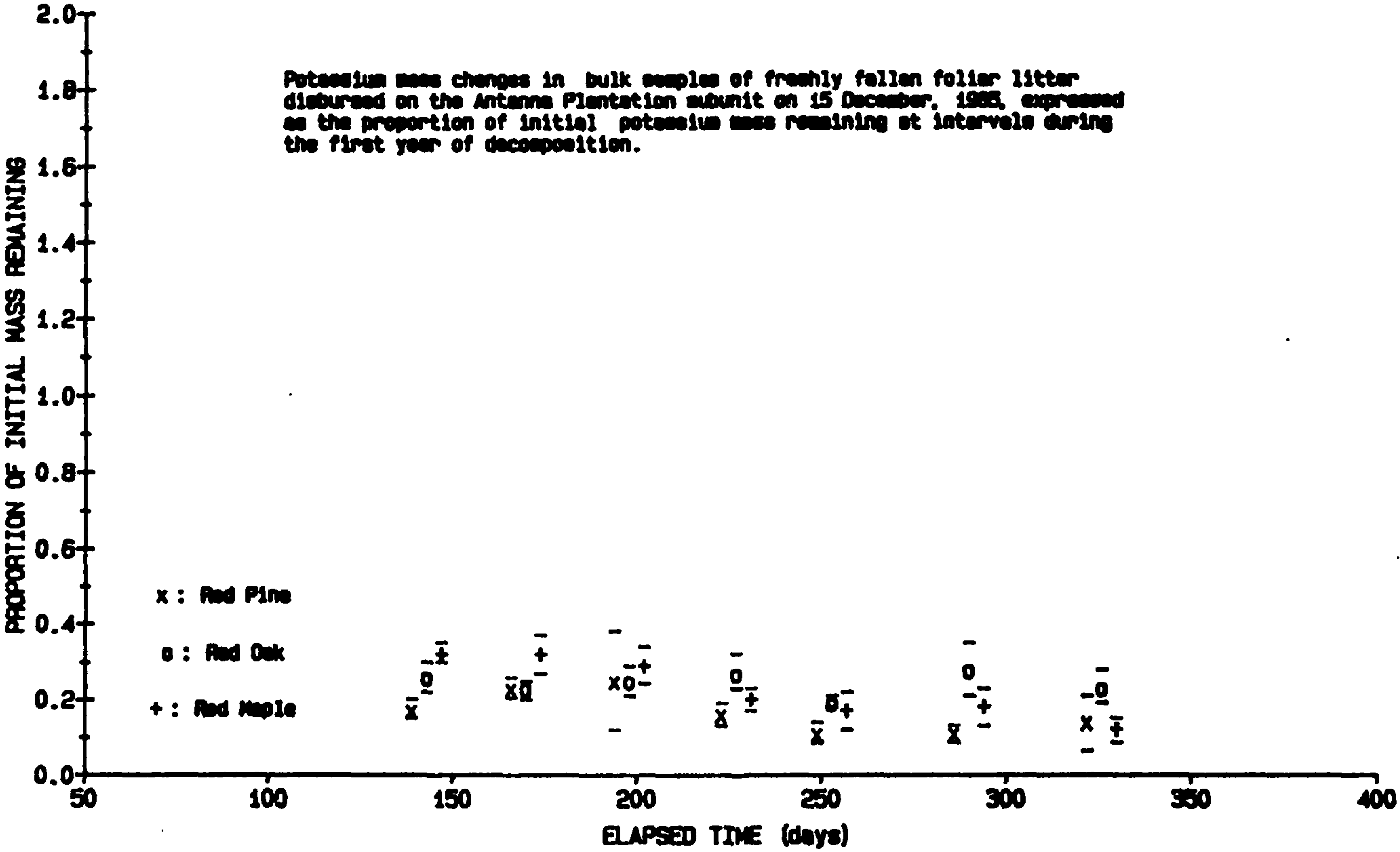


FIGURE 60. **BULK FOLIAR LITTER SAMPLES, ANTENNA PLANTATION**

PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1985-1986)



Potassium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Antenna Plantation subunit on 15 December, 1985, expressed as the proportion of initial potassium mass remaining at intervals during the first year of decomposition.

FIGURE 61.

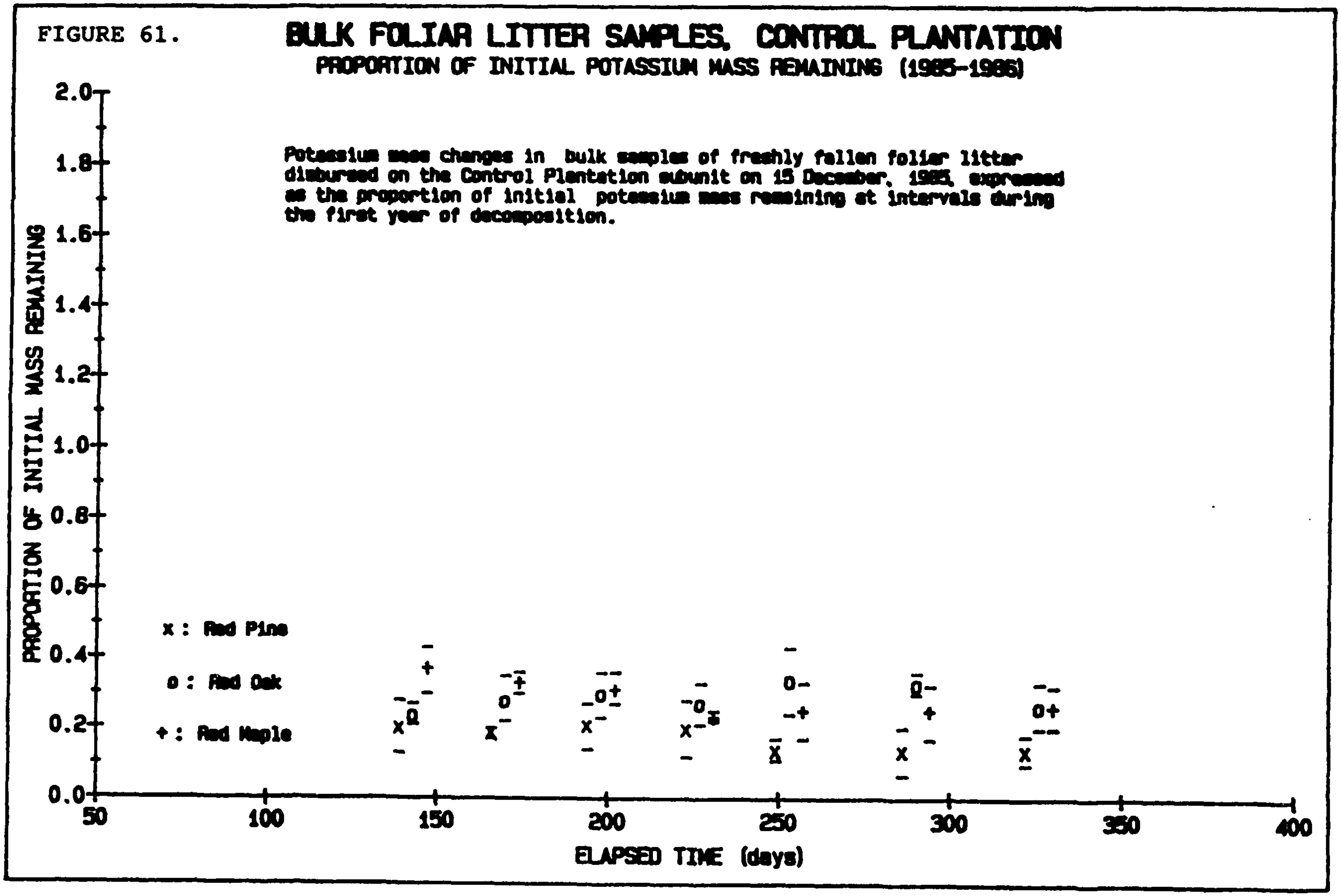
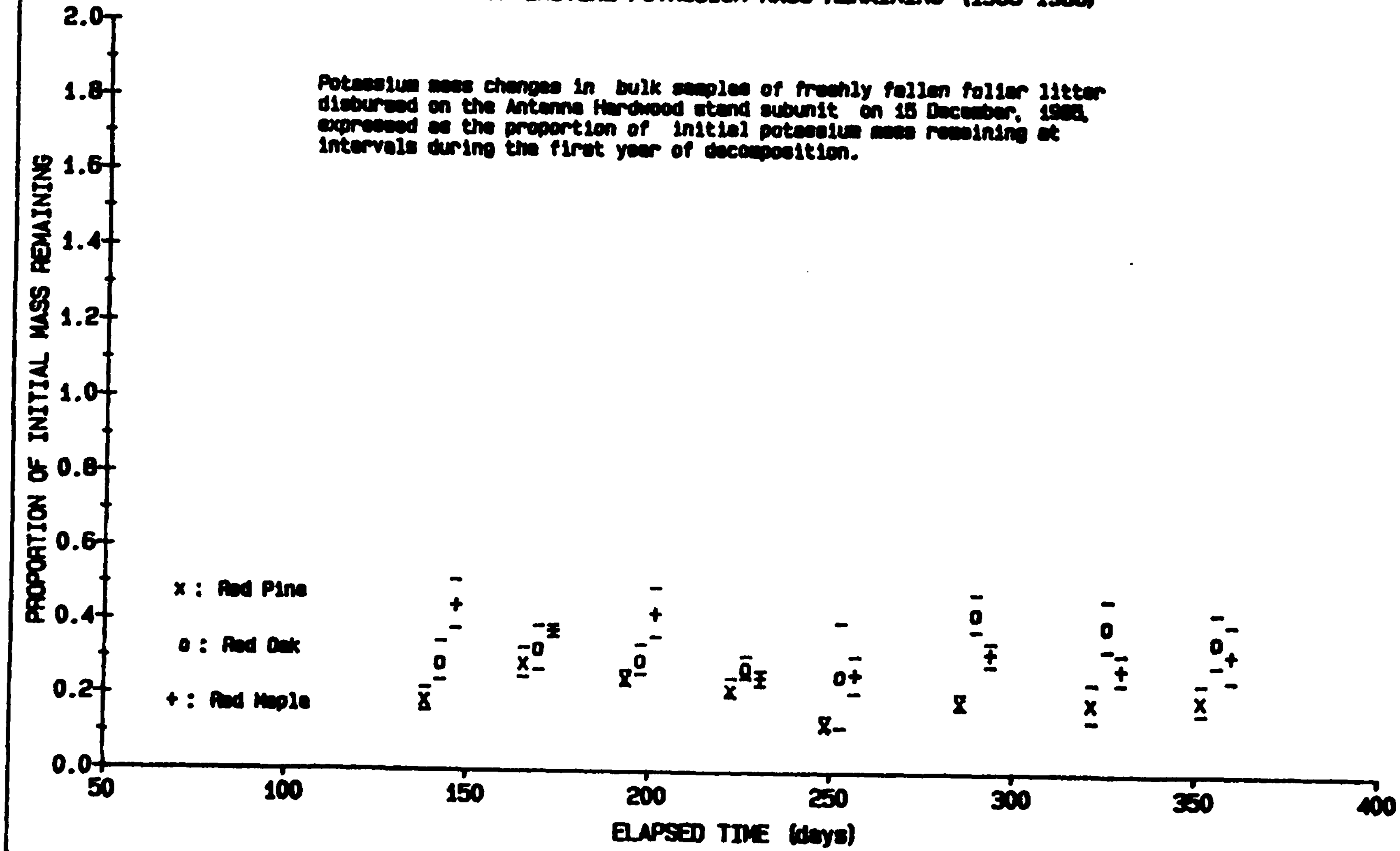

BULK FOLIAR LITTER SAMPLES, CONTROL PLANTATION
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1985-1986)
Potassium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Control Plantation subunit on 15 December, 1985, expressed as the proportion of initial potassium mass remaining at intervals during the first year of decomposition.
x : Red Pine
o : Red Oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 62. **BULK FOLIAR LITTER SAMPLES, ANTENNA HARDWOOD STAND**

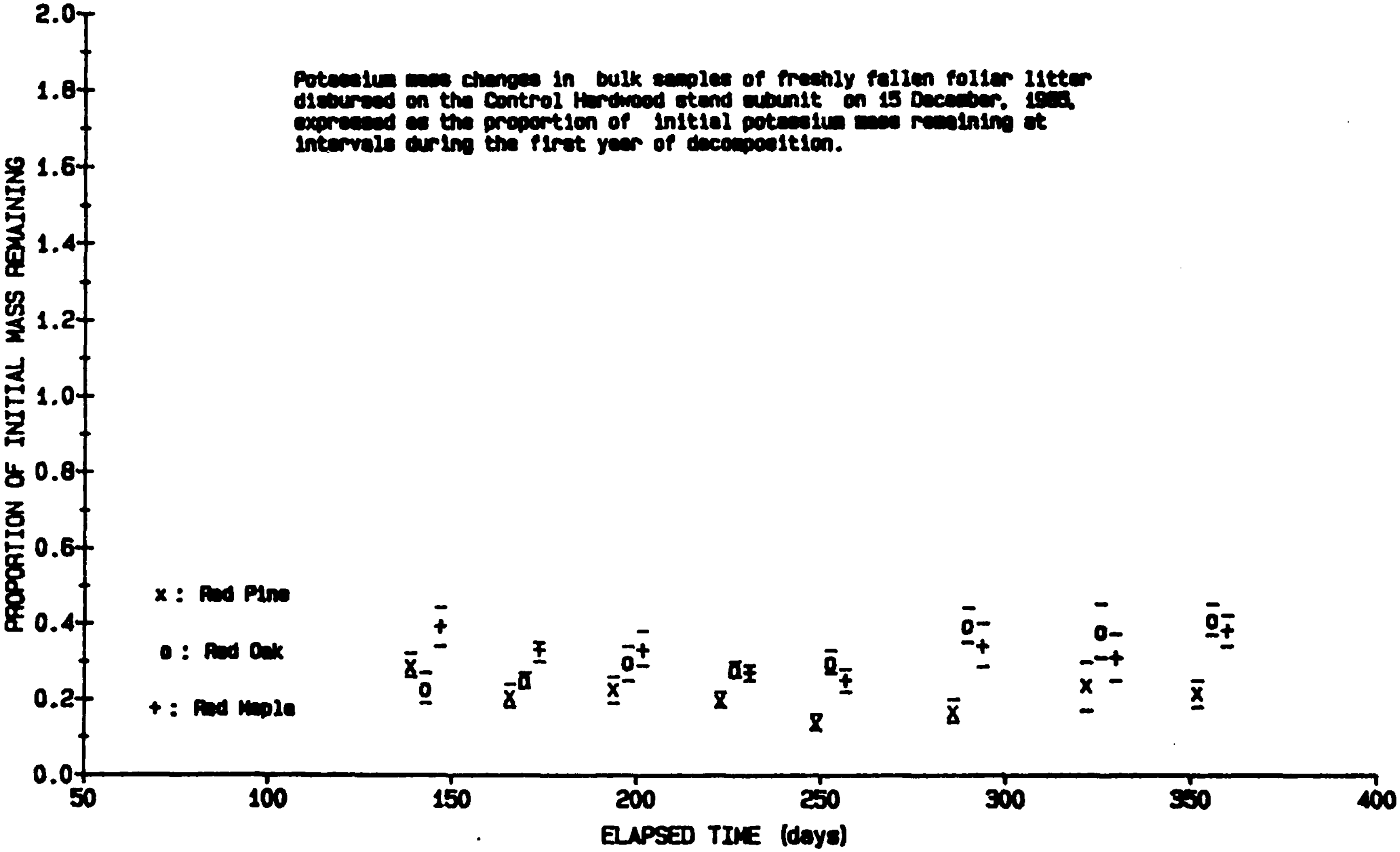
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1985-1986)



Potassium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Antenna Hardwood stand subunit on 15 December, 1985, expressed as the proportion of initial potassium mass remaining at intervals during the first year of decomposition.

FIGURE 63. **BULK FOLIAR LITTER SAMPLES, CONTROL HARDWOOD STAND**

PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1985-1986)



Potassium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Control Hardwood stand subunit on 15 December, 1985, expressed as the proportion of initial potassium mass remaining at intervals during the first year of decomposition.

FIGURE 64.

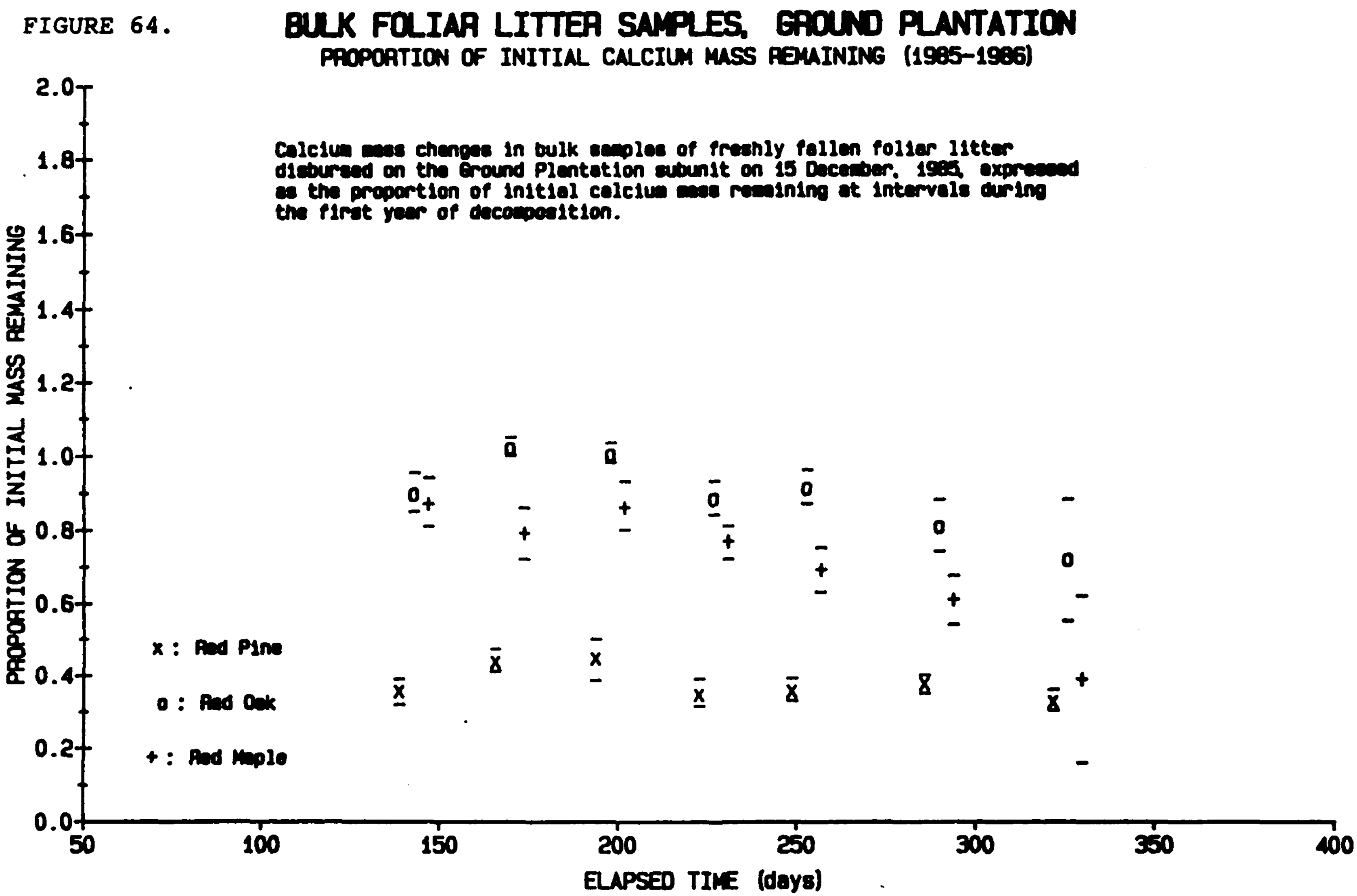

BULK FOLIAR LITTER SAMPLES, GROUND PLANTATION
PROPORTION OF INITIAL CALCIUM MASS REMAINING (1985-1986)
Calcium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Ground Plantation subunit on 15 December, 1985, expressed as the proportion of initial calcium mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Red Pine
o : Red Oak
+ : Red Maple
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 65.

BULK FOLIAR LITTER SAMPLES, ANTENNA PLANTATION

PROPORTION OF INITIAL CALCIUM MASS REMAINING (1985-1986)

Calcium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Antenna Plantation subunit on 15 December, 1985, expressed as the proportion of initial calcium mass remaining at intervals during the first year of decomposition.

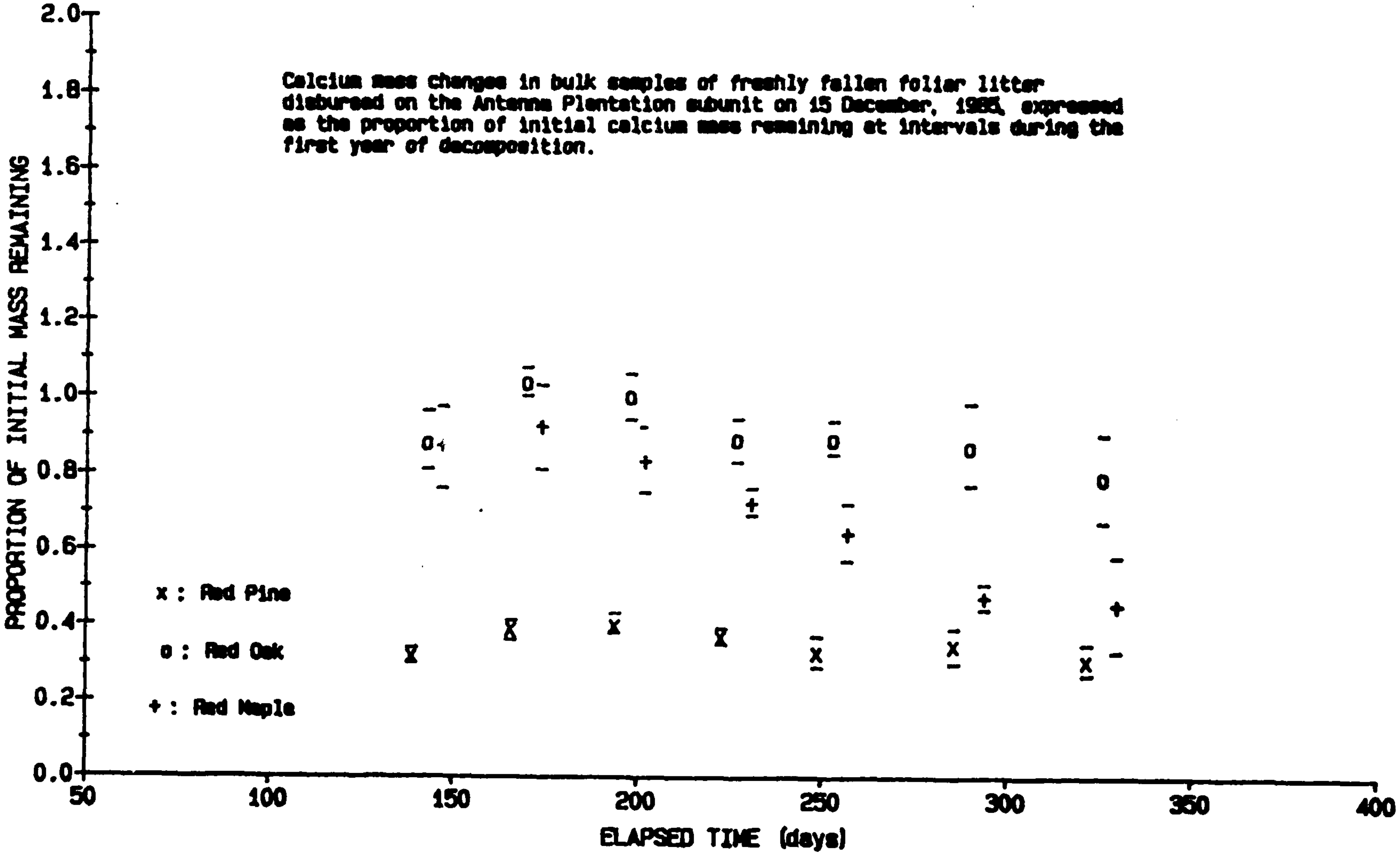


FIGURE 66.

BULK FOLIAR LITTER SAMPLES, CONTROL PLANTATION

PROPORTION OF INITIAL CALCIUM MASS REMAINING (1985-1986)

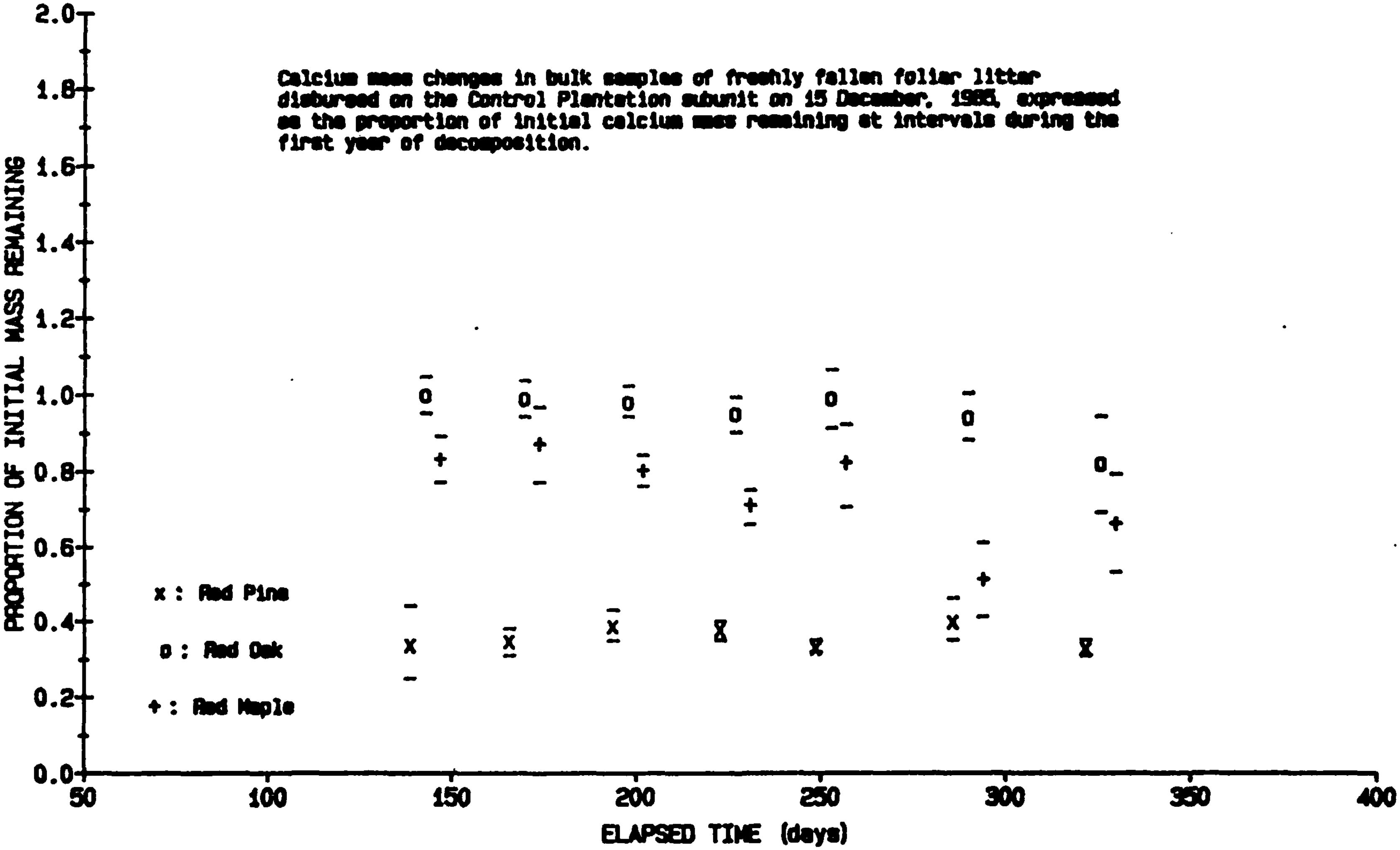


FIGURE 67. **BULK FOLIAR LITTER SAMPLES, ANTENNA HARDWOOD STAND**

PROPORTION OF INITIAL CALCIUM MASS REMAINING (1985-1986)

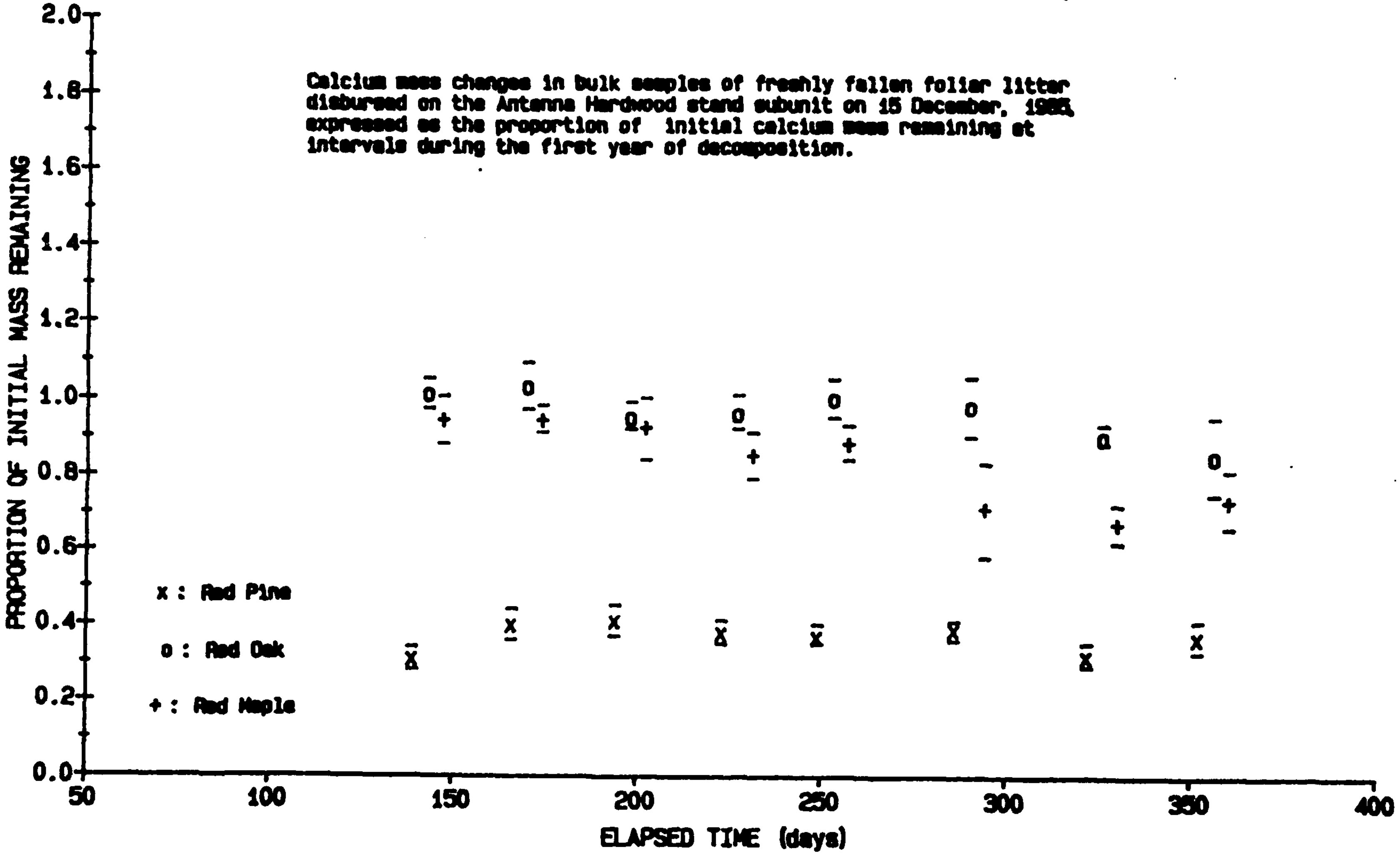


FIGURE 68. **BULK FOLIAR LITTER SAMPLES, CONTROL HARDWOOD STAND**

PROPORTION OF INITIAL CALCIUM MASS REMAINING (1985-1986)

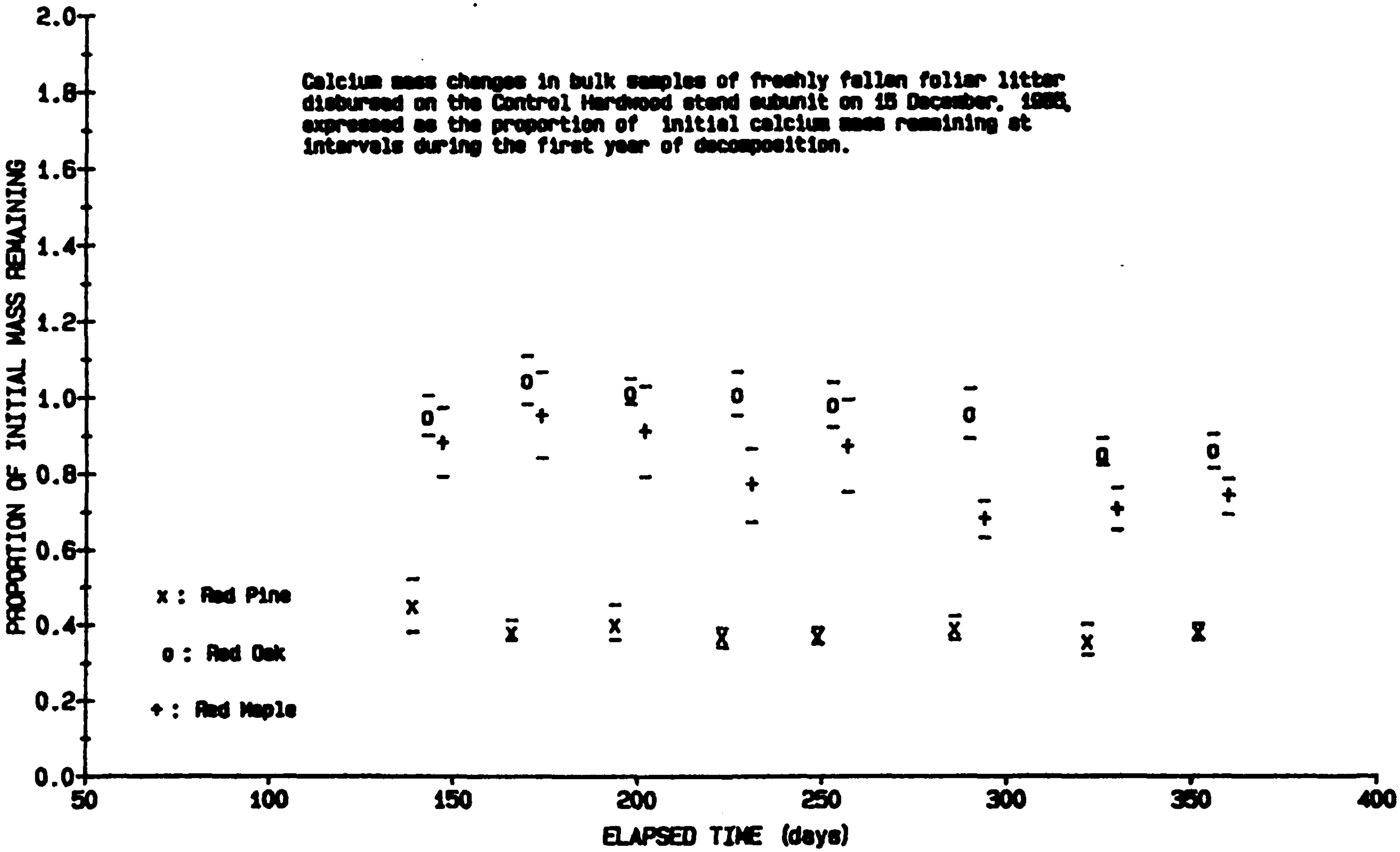


FIGURE 69.

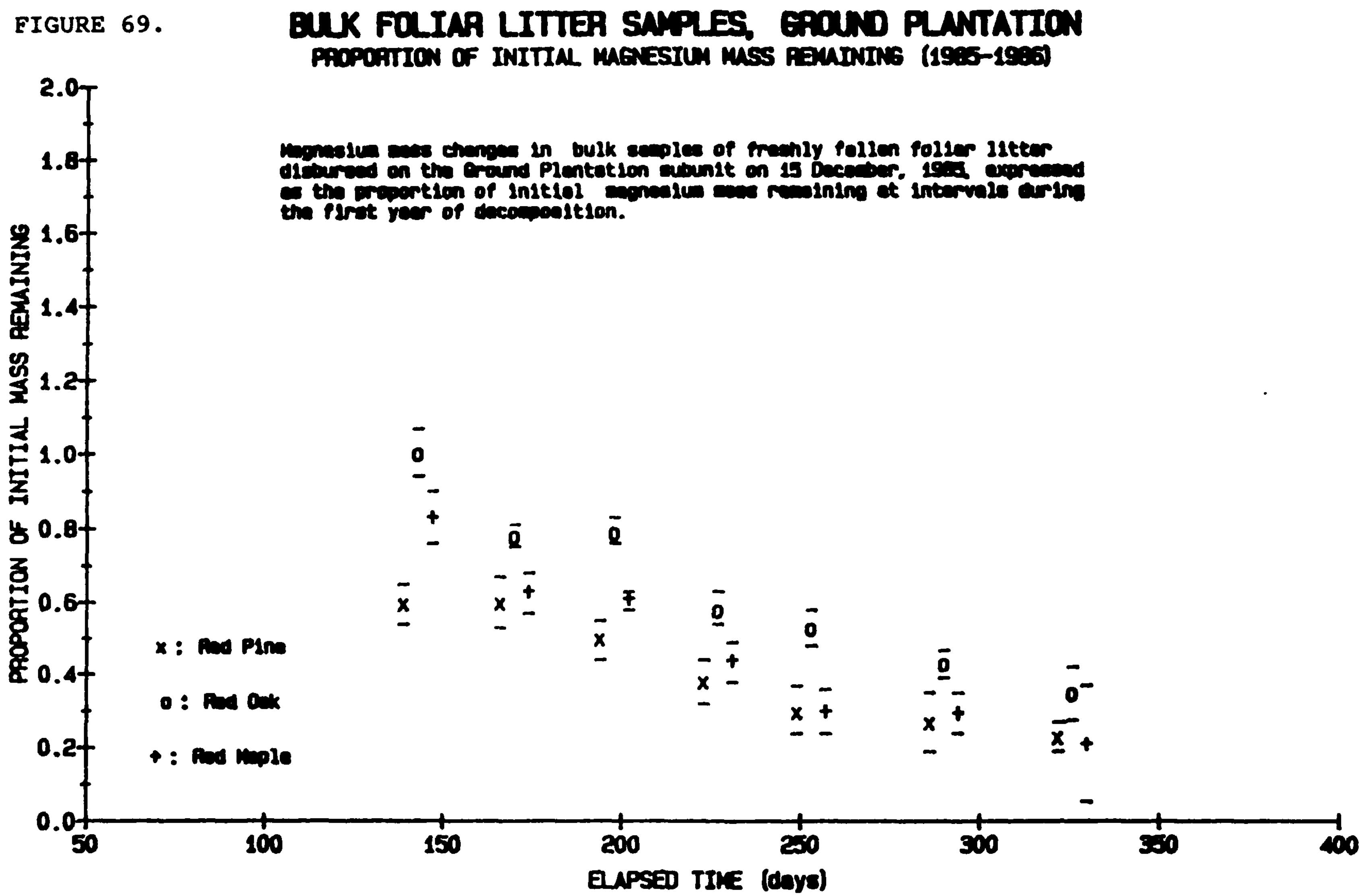

BULK FOLIAR LITTER SAMPLES, GROUND PLANTATION
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1985-1986)
Magnesium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Ground Plantation subunit on 15 December, 1985, expressed as the proportion of initial magnesium mass remaining at intervals during the first year of decomposition.
x : Red Pine
o : Red Oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 70.

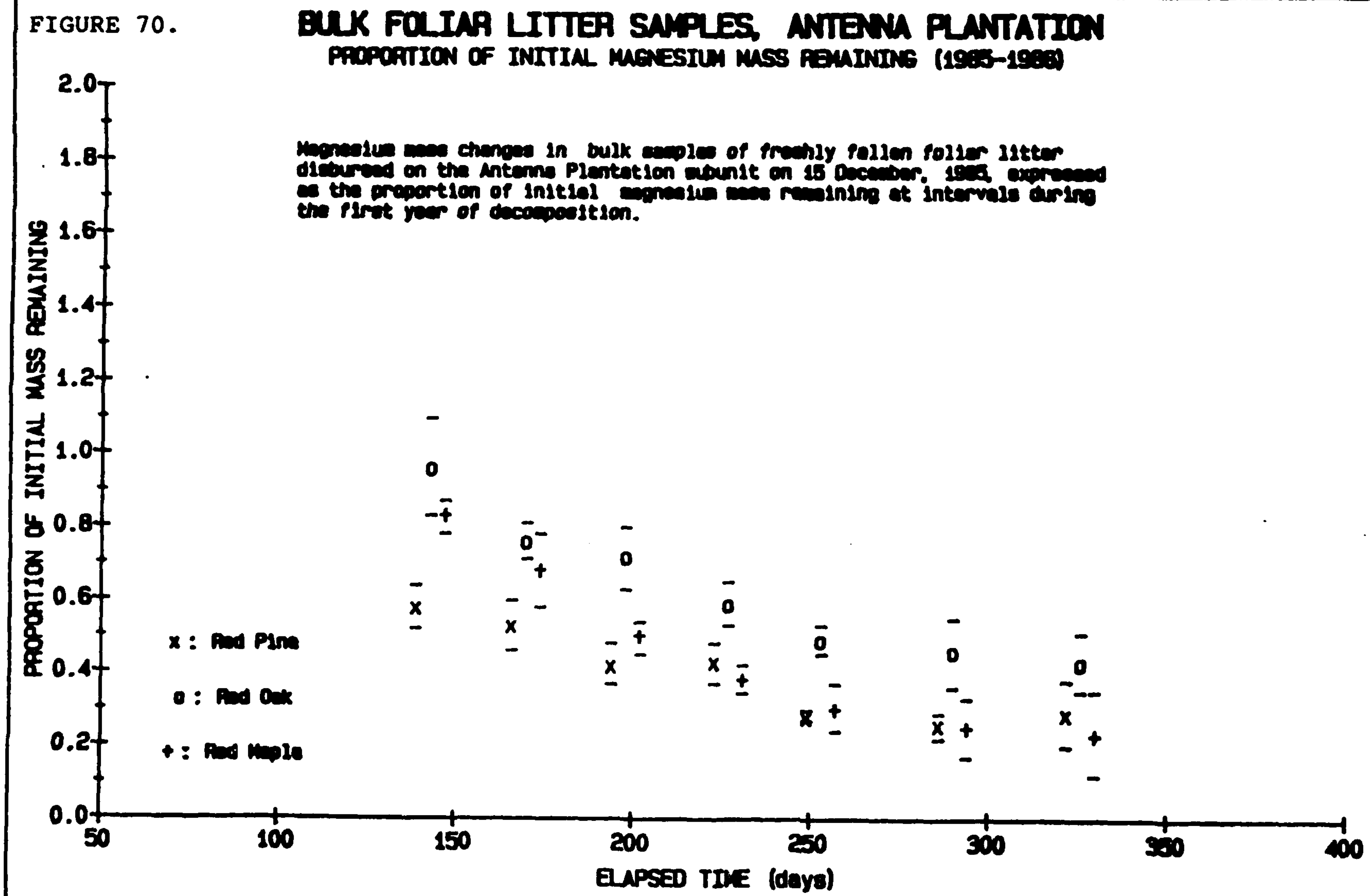

BULK FOLIAR LITTER SAMPLES, ANTENNA PLANTATION
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1985-1986)
Magnesium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Antenna Plantation subunit on 15 December, 1985, expressed as the proportion of initial magnesium mass remaining at intervals during the first year of decomposition.
x : Red Pine
o : Red Oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
ELAPSED TIME (days)
50
100
150
200
250
300
350
400

FIGURE 71.

BULK FOLIAR LITTER SAMPLES, CONTROL PLANTATION

PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1985-1986)

Magnesium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Control Plantation subunit on 15 December, 1985, expressed as the proportion of initial magnesium mass remaining at intervals during the first year of decomposition.

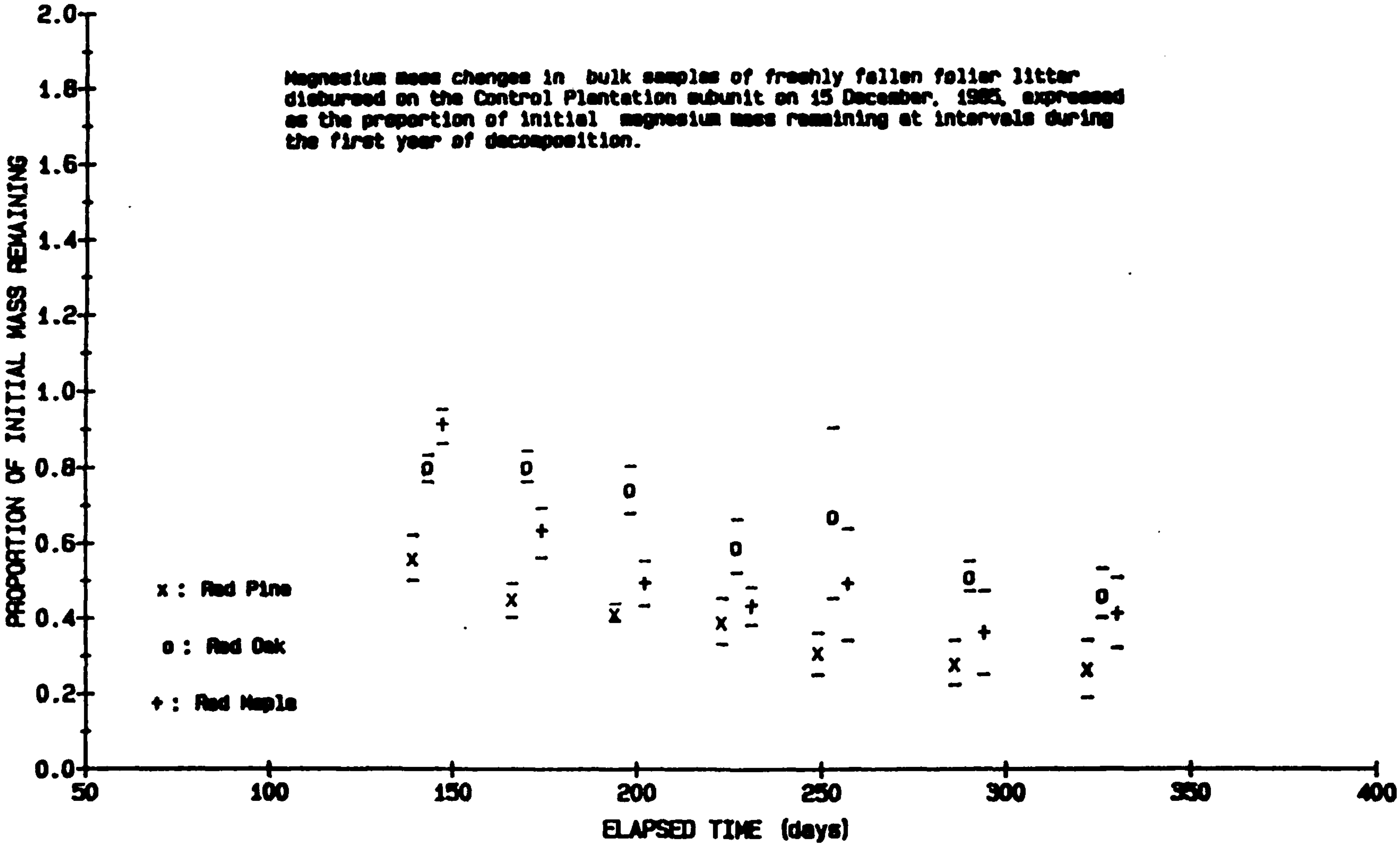


FIGURE 72. **BULK FOLIAR LITTER SAMPLES, ANTENNA HARDWOOD STAND**

PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1985-1986)

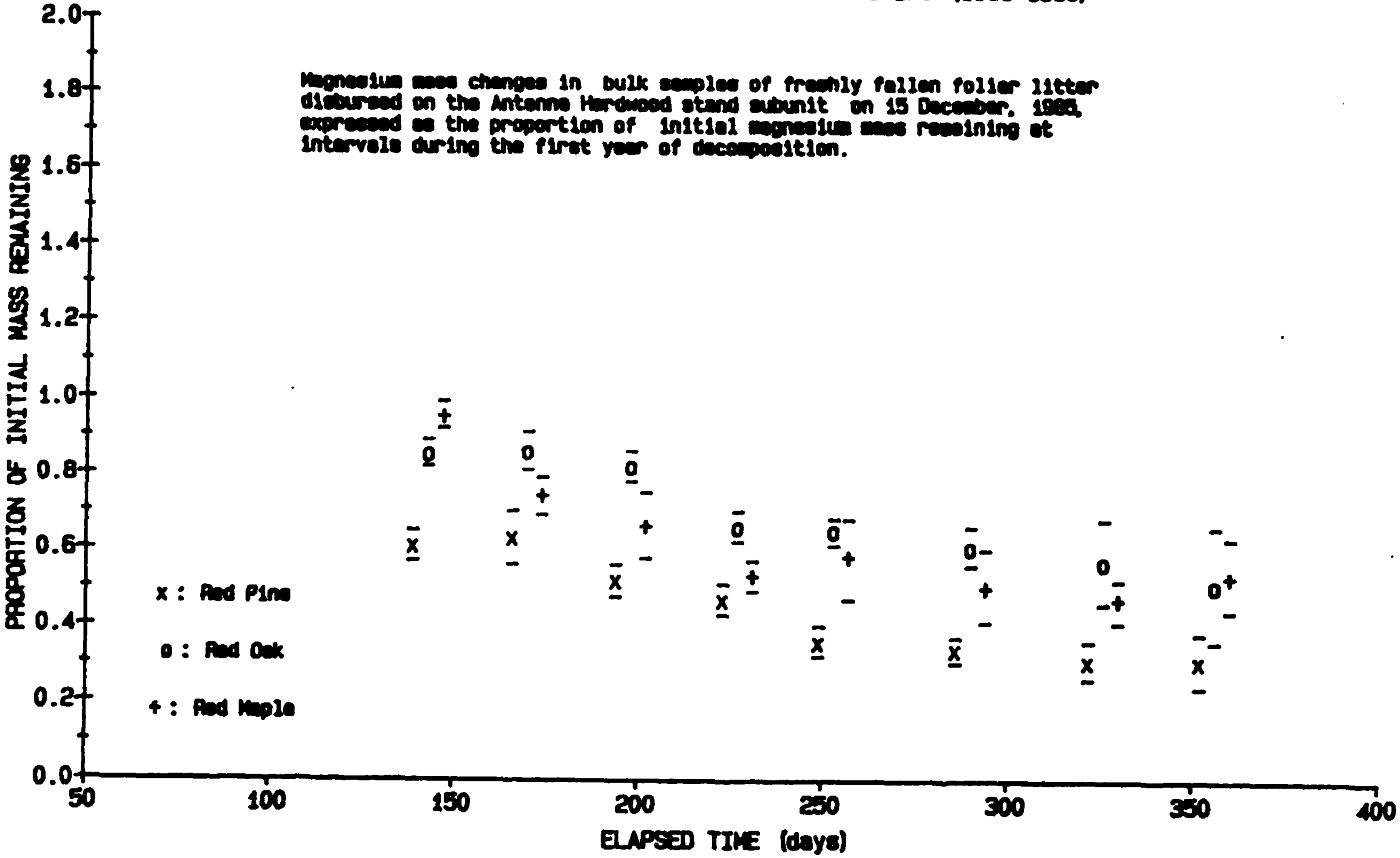
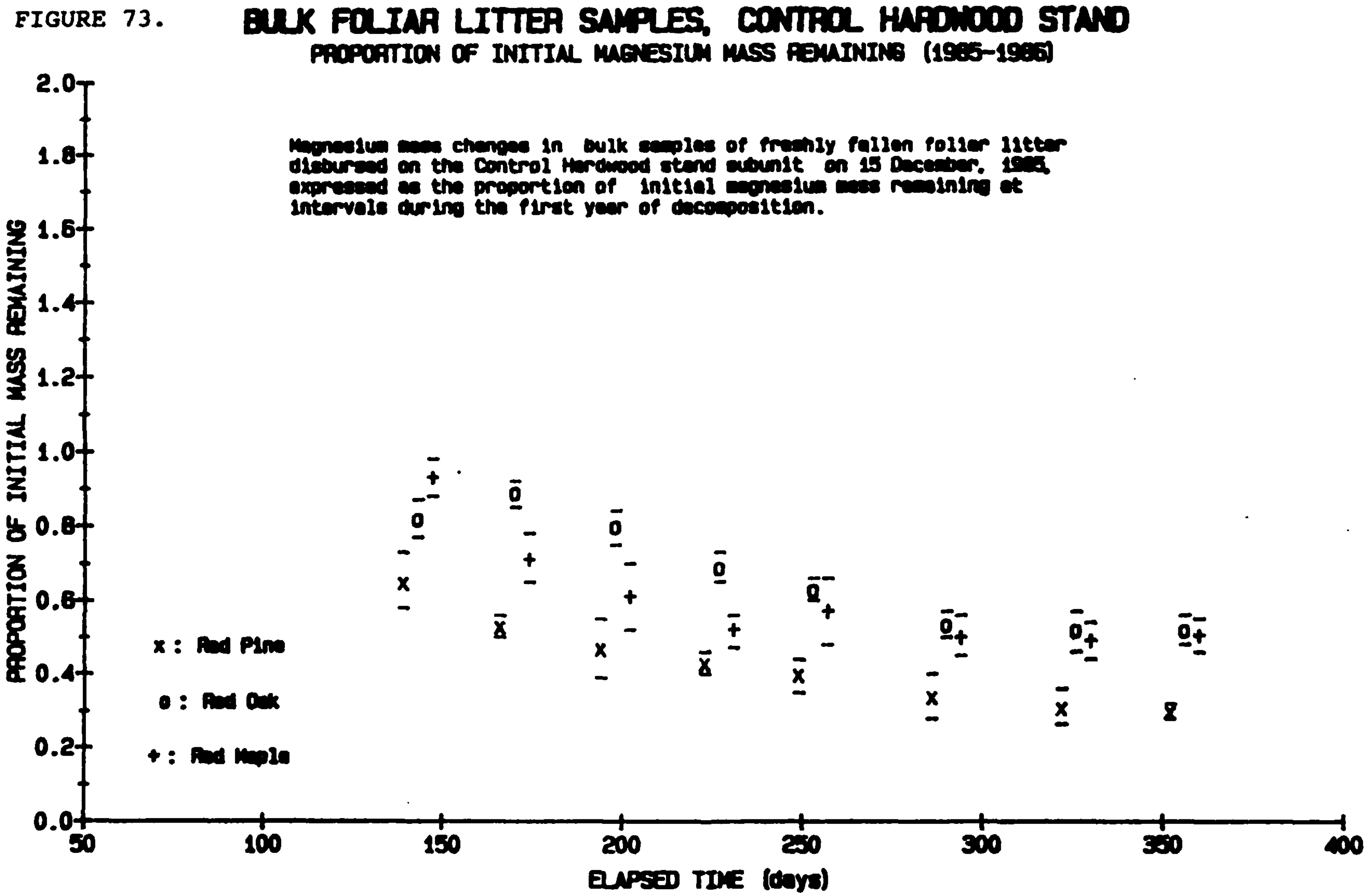


FIGURE 73.


BULK FOLIAR LITTER SAMPLES, CONTROL HARDWOOD STAND
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1985-1986)
Magnesium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Control Hardwood stand subunit on 15 December, 1985, expressed as the proportion of initial magnesium mass remaining at intervals during the first year of decomposition.
x : Red Pine
o : Red Oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

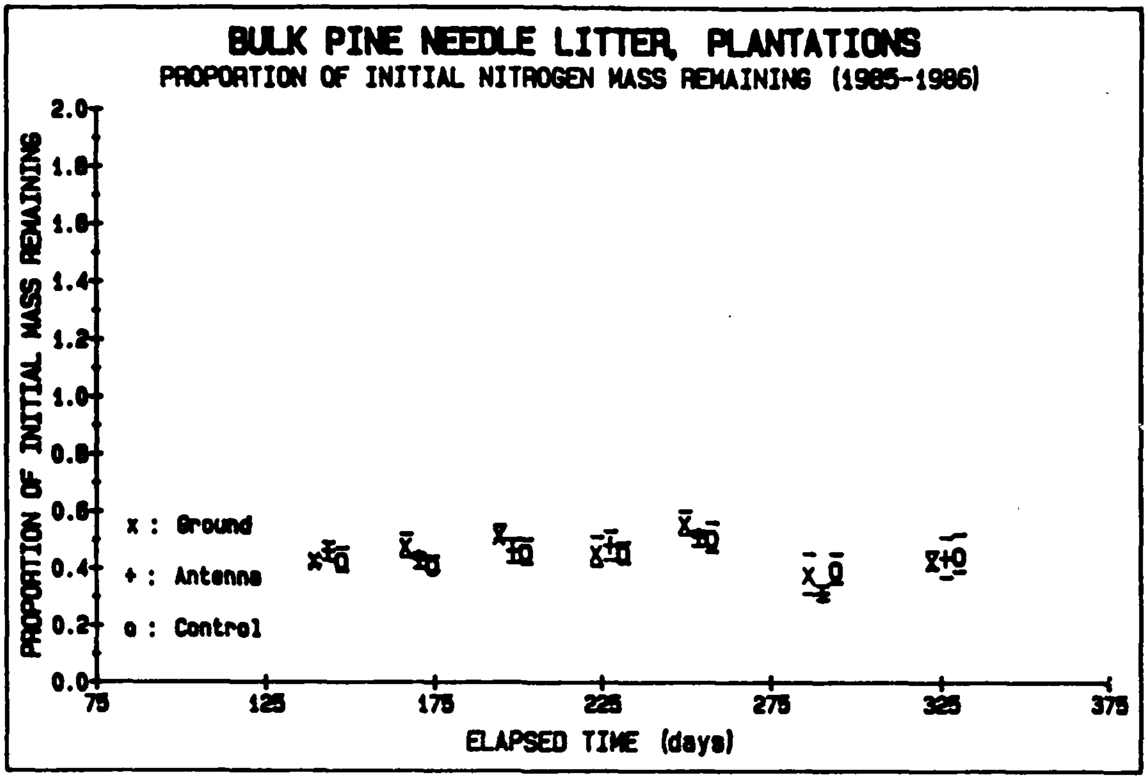
their physical and chemical compositions. These differences in litter substrate, in turn, may select for substantially different decomposer communities, both functionally and taxonomically. As a result, the likelihood of detecting any effects of environmental perturbations are enhanced by studying decomposition of all three litter species rather than only one or two of them.

Seasonal progress of N flux for the bulk pine samples retrieved from the plantation and hardwood stand subunits during the 1985-86 study are presented in Figures 74a and 74b. Corresponding data for the 1984-85 study are presented in Figures 75a and 75b. Comparisons of yearly N flux patterns for the bulk pine samples retrieved from the three plantation and two hardwood stand subunits are presented in Figures 76 - 80, respectively. Analogous representations of subunit and yearly comparisons of nutrient fluxes for bulk pine samples are presented in Figures 81 - 87 for P, Figures 88 - 94 for K, Figures 95 - 101 for Ca, and Figures 102 - 108 for Mg. For bulk oak samples, subunit and yearly comparisons of nutrient fluxes are presented as Figures 109 - 115 for N, Figures 116 - 122 for P, Figures 123 - 129 for K, Figures 130 - 136 for Ca, and Figures 137 - 143 for Mg. Finally, subunit and yearly comparisons of nutrient flux for bulk maple litter are presented as Figures 144 - 150 for N, Figures 151 - 157 for P, Figures 158 - 164 for K, Figures 165 - 171 for Ca, and Figures 172 - 178 for Mg.

Analysis of the nutrient flux data is still incomplete. X values relate remaining nutrient content to initial nutrient content of the sample; percent nutrient content is not corrected for dry matter mass loss. X values relate meaningfully to nutrient losses (or gains) during litter decomposition, while percentages may prove more useful as covariates related to dry matter mass loss. The striking differences in yearly patterns of nutrient flux, especially for pine and oak, suggest that nutrient content may be related to yearly differences in decomposition rate. Also, differences in nutrient levels of background litter at the study sites may be more important than the initial nutrient levels of the experimental materials. Bulk oak samples in the 1984-85

study contained less initial N than those in the 1985-86 study, yet samples retrieved during 1985 contained more N than did those retrieved during 1986.

The relationships between nutrient content of bulk litter samples and seasonal progress in mass loss were evaluated by correlation analysis. Tables 132 - 134 present correlation coefficients with their attained levels of significance for pine, oak, and maple samples from the 1985 and 1986 studies, and for pooled data from both studies. N, P, Ca and Mg levels of retrieved pine samples were significantly correlated with the degree of mass loss attained. N, P, K, Ca and Mg levels of retrieved oak samples were likewise significantly correlated with attained mass loss. Maple sample mass loss progress was generally well correlated with N, P, K and Mg content. Significant N, P and Ca correlation coefficients were negative, indicating that levels of these nutrients generally increased with decomposition progress measured as the proportion of initial dry matter mass remaining. Significant Mg correlation coefficients were positive, indicating that Mg level declined as decomposition progressed. During 1988, nutrient levels will be tested for possible use as covariates to help explain differences among years in rates of dry matter mass loss .


BULK PINE NEEDLE LITTER, PLANTATIONS
PROPORTION OF INITIAL NITROGEN MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

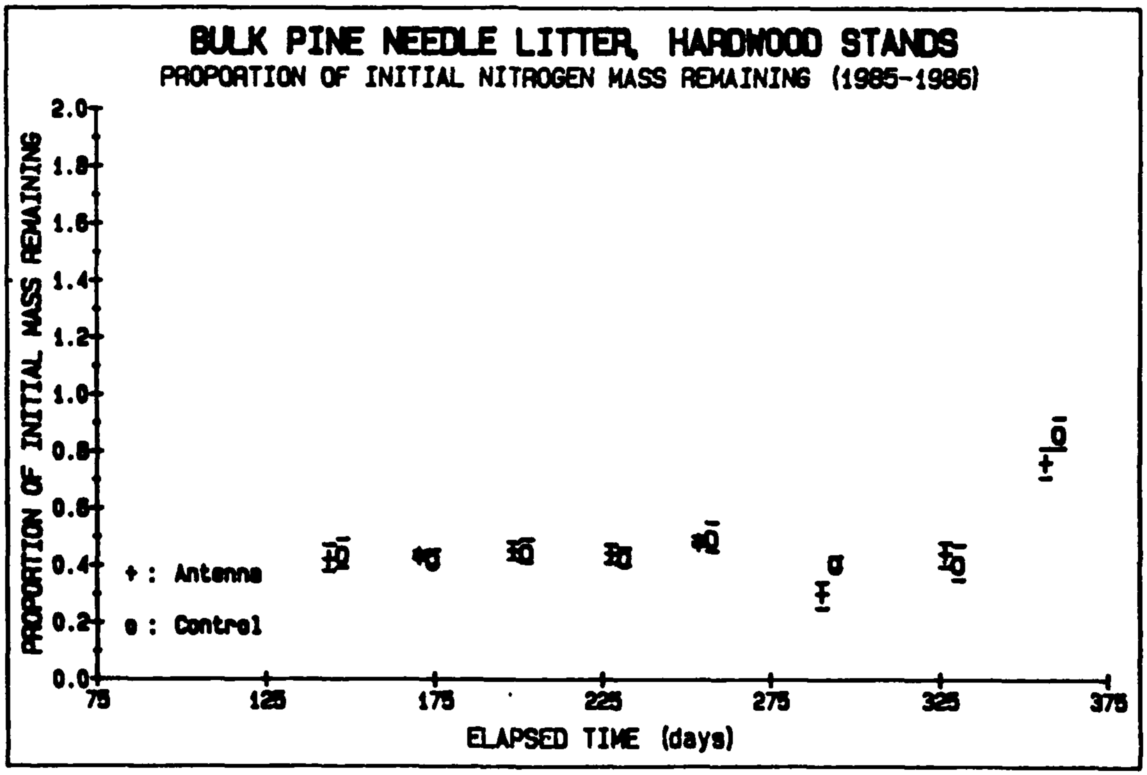
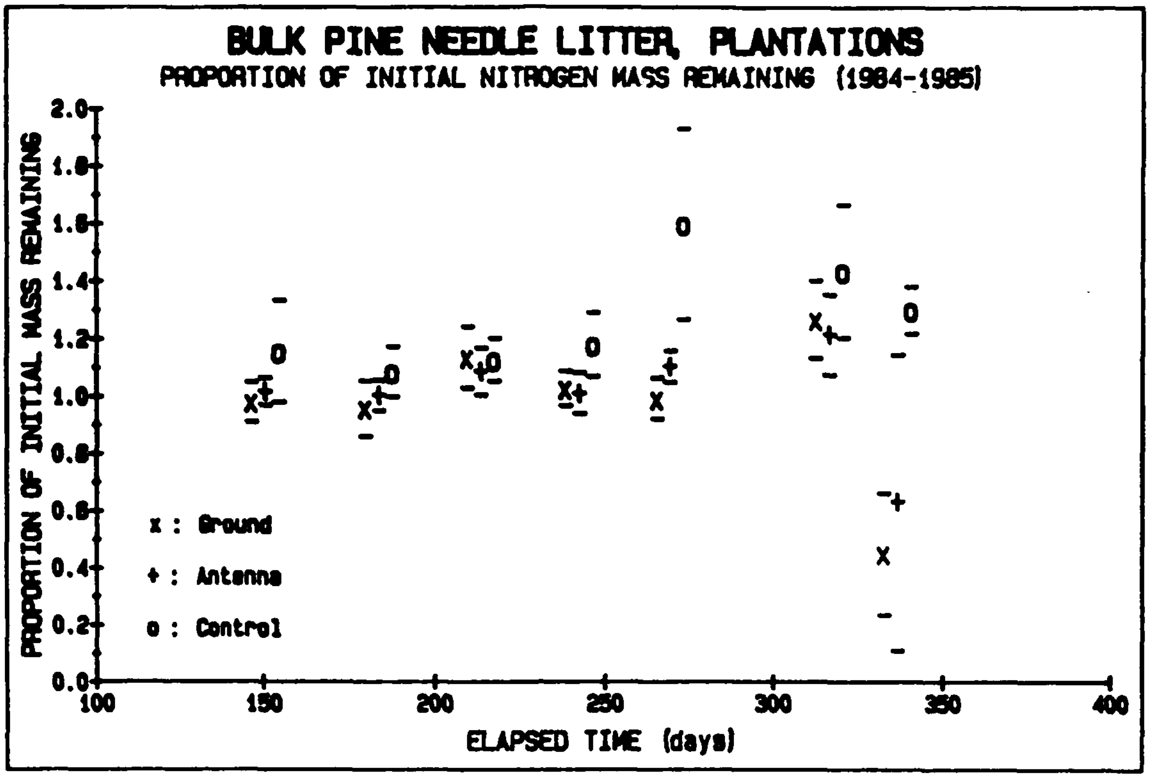

BULK PINE NEEDLE LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL NITROGEN MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

FIGURE 74.


BULK PINE NEEDLE LITTER, PLANTATIONS
PROPORTION OF INITIAL NITROGEN MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control

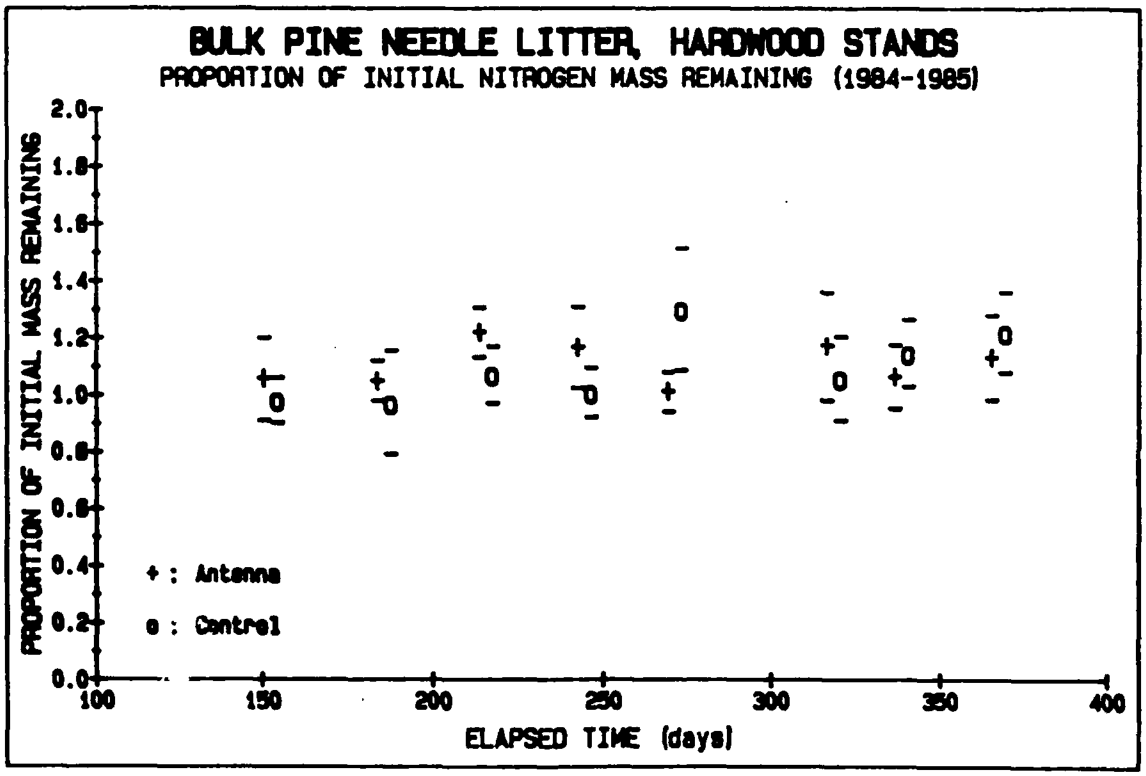

BULK PINE NEEDLE LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL NITROGEN MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
+ : Antenna
o : Control

FIGURE 75.

FIGURE 76.

BULK PINE LITTER, GROUND PLANTATION

PROPORTION OF INITIAL NITROGEN MASS REMAINING

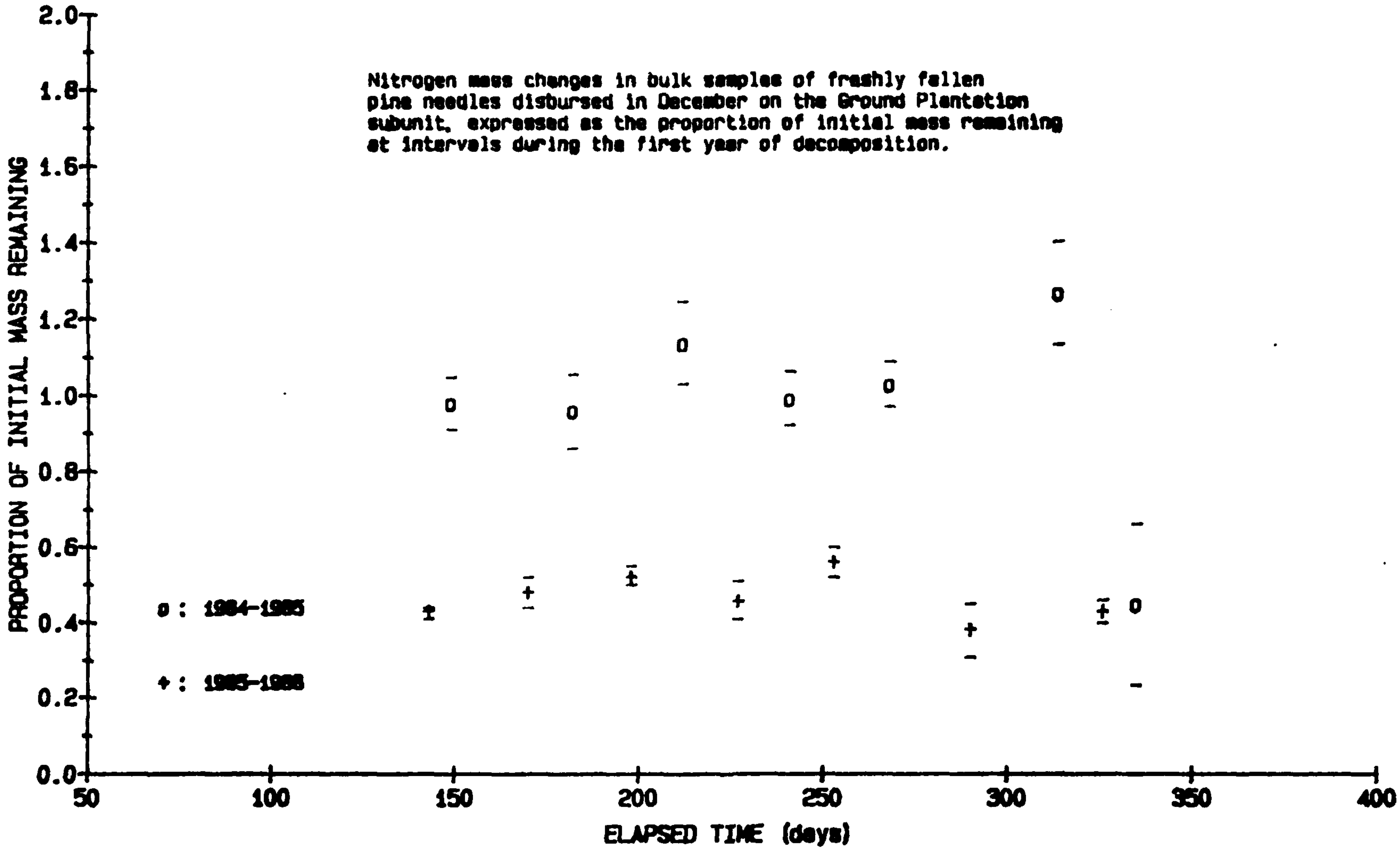


FIGURE 77.

BULK PINE LITTER, ANTENNA PLANTATION

PROPORTION OF INITIAL NITROGEN MASS REMAINING

Nitrogen mass changes in bulk samples of freshly fallen pine needles disbursed in December on the Antenna Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

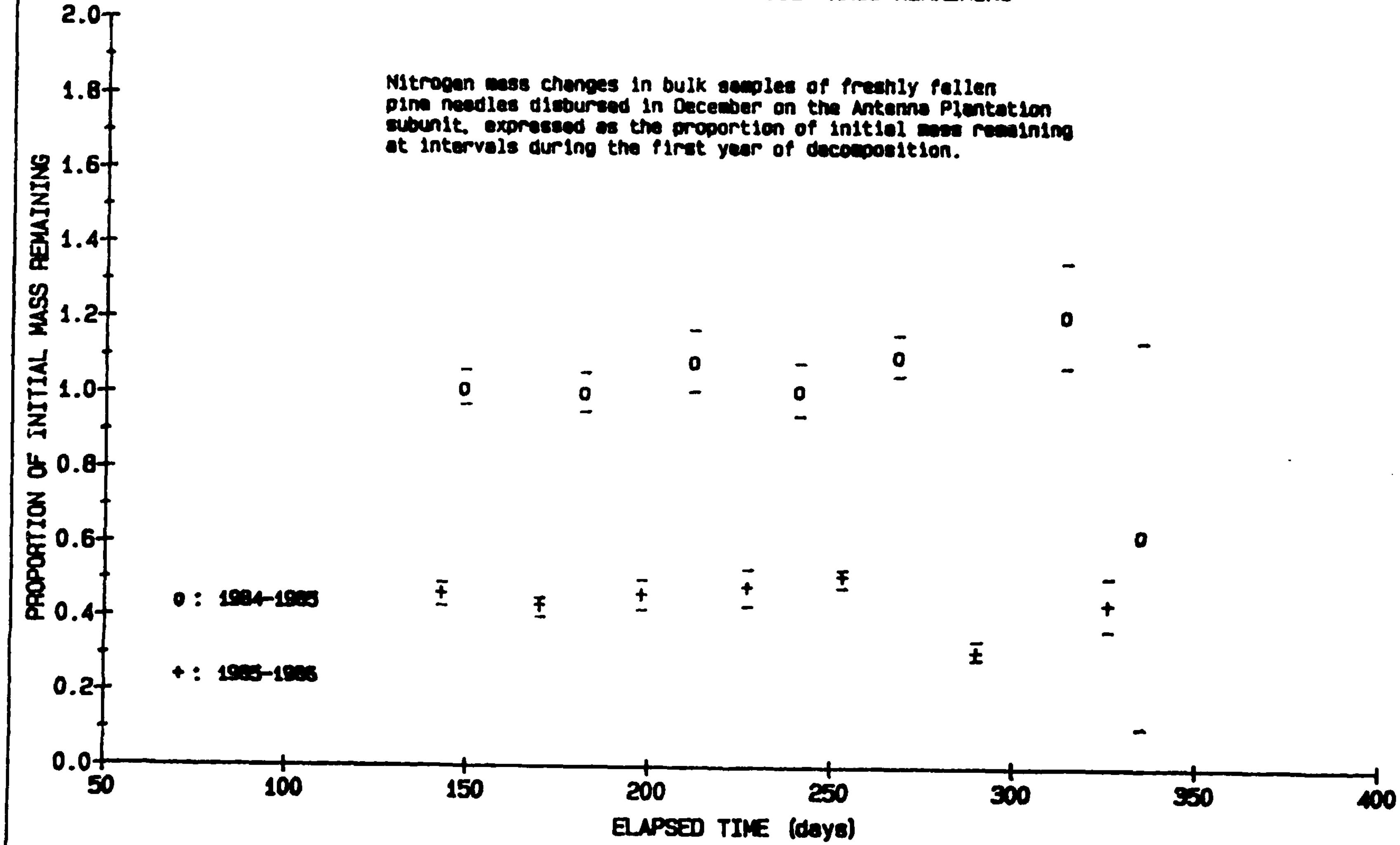


FIGURE 78.

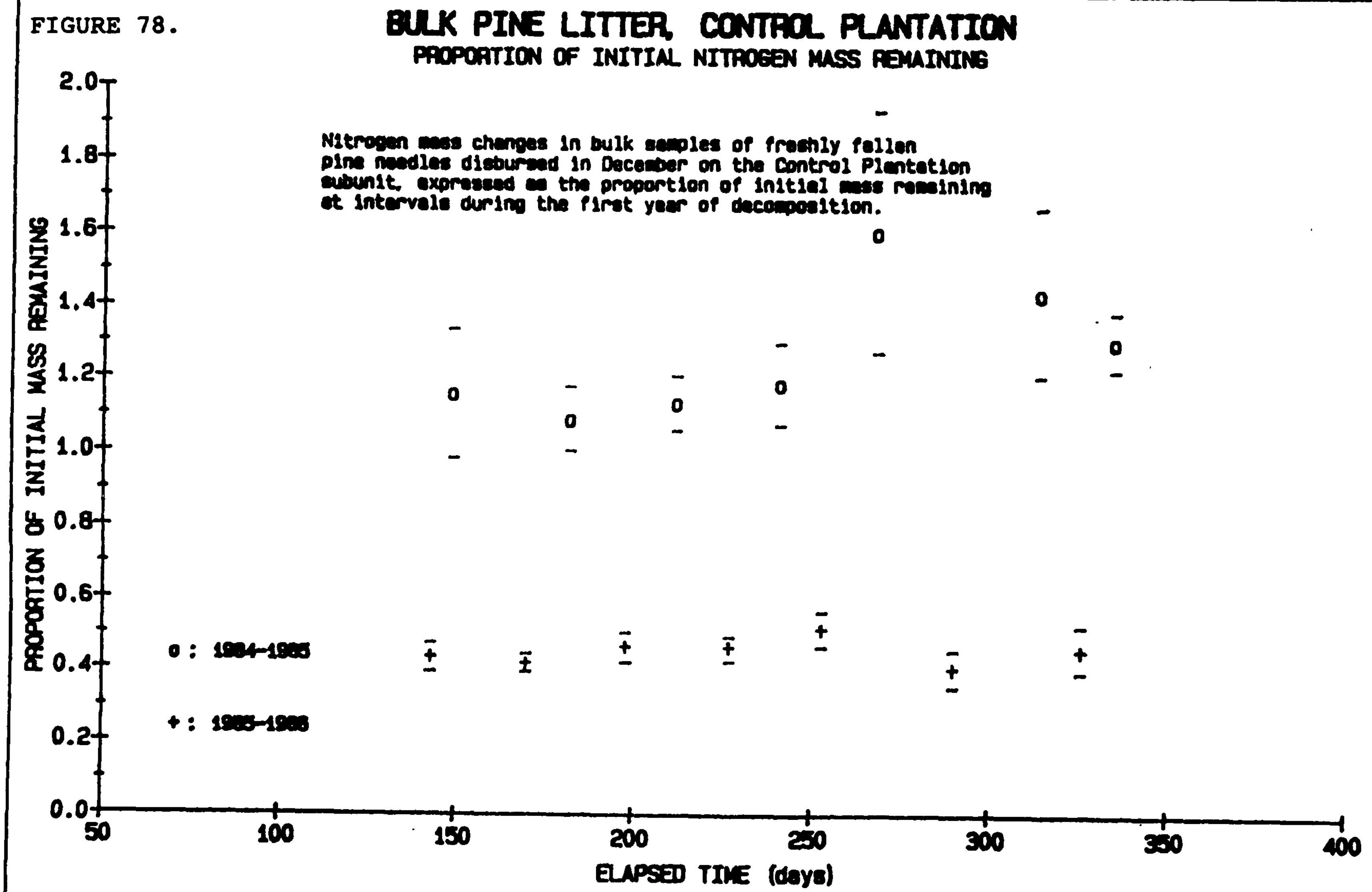

BULK PINE LITTER, CONTROL PLANTATION
PROPORTION OF INITIAL NITROGEN MASS REMAINING
Nitrogen mass changes in bulk samples of freshly fallen pine needles disbursed in December on the Control Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
o : 1984-1985
+ : 1985-1986
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
50
100
150
200
250
300
350
400

FIGURE 79. **BULK PINE LITTER, ANTENNA HARDWOOD STAND**

PROPORTION OF INITIAL NITROGEN MASS REMAINING

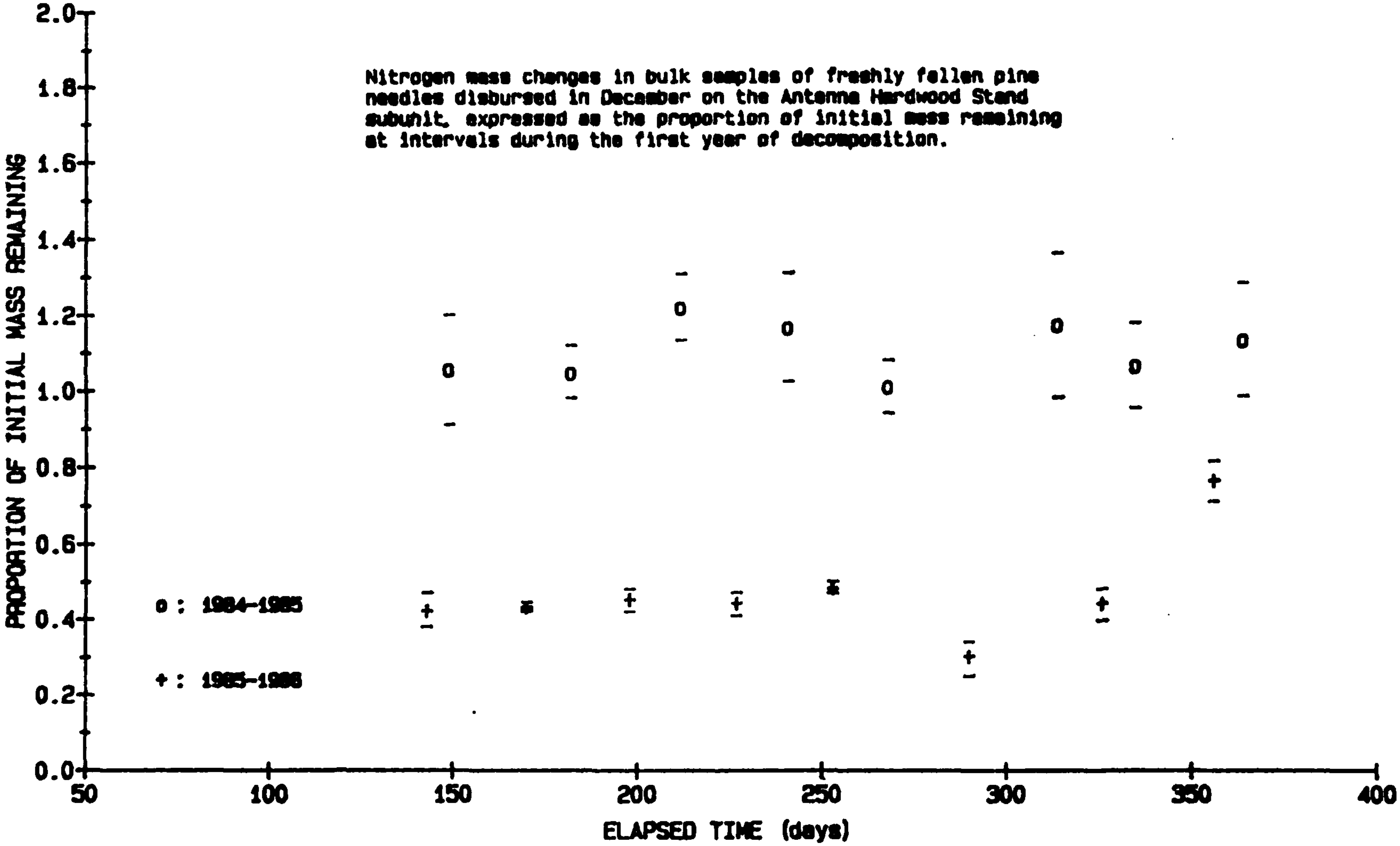
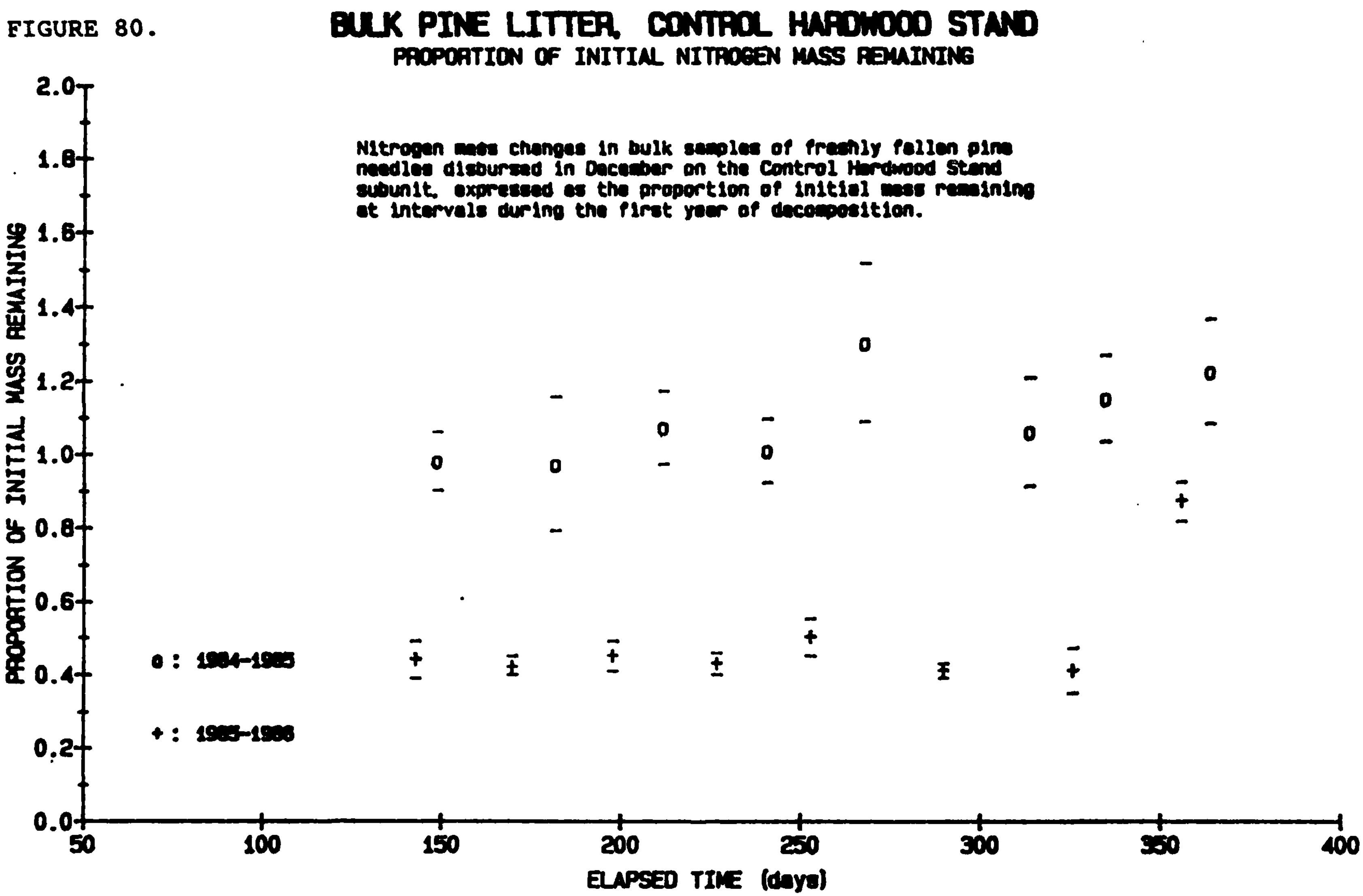
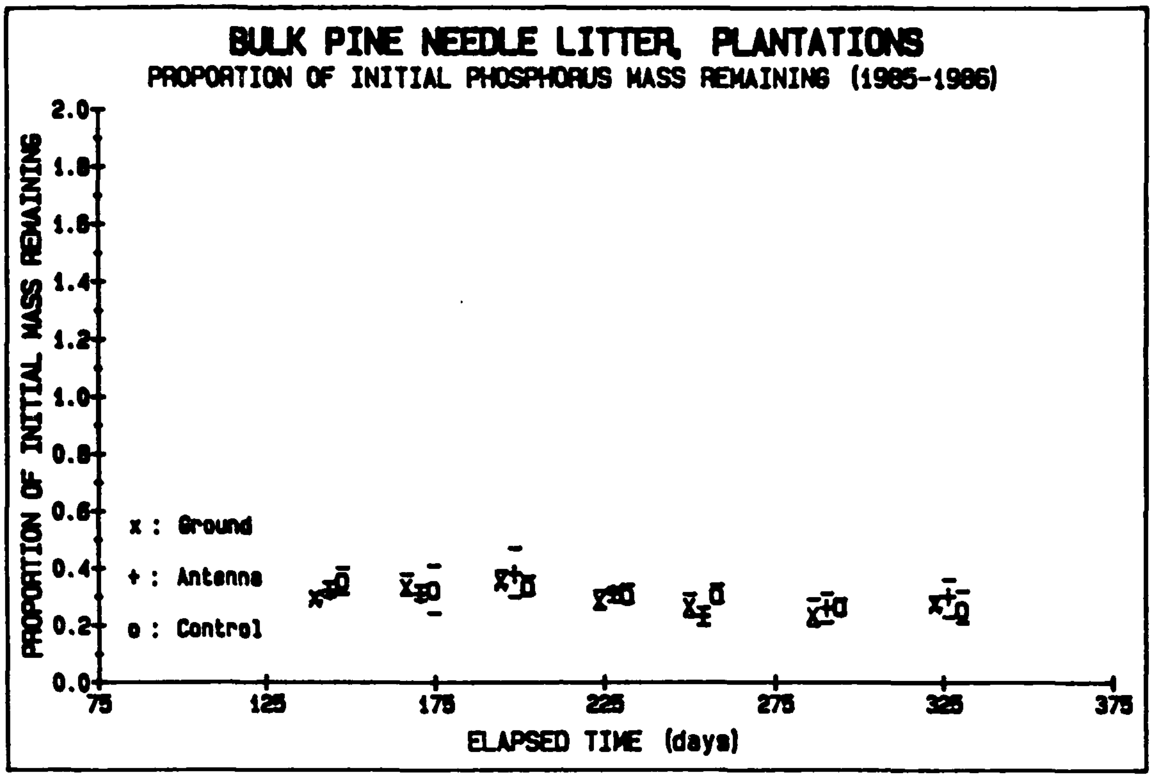


FIGURE 80.


BULK PINE LITTER, CONTROL HARDWOOD STAND
PROPORTION OF INITIAL NITROGEN MASS REMAINING
Nitrogen mass changes in bulk samples of freshly fallen pine needles disbursed in December on the Control Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
o : 1984-1985
+ : 1985-1986
50
100
150
200
250
300
350
400
ELAPSED TIME (days)


BULK PINE NEEDLE LITTER, PLANTATIONS
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

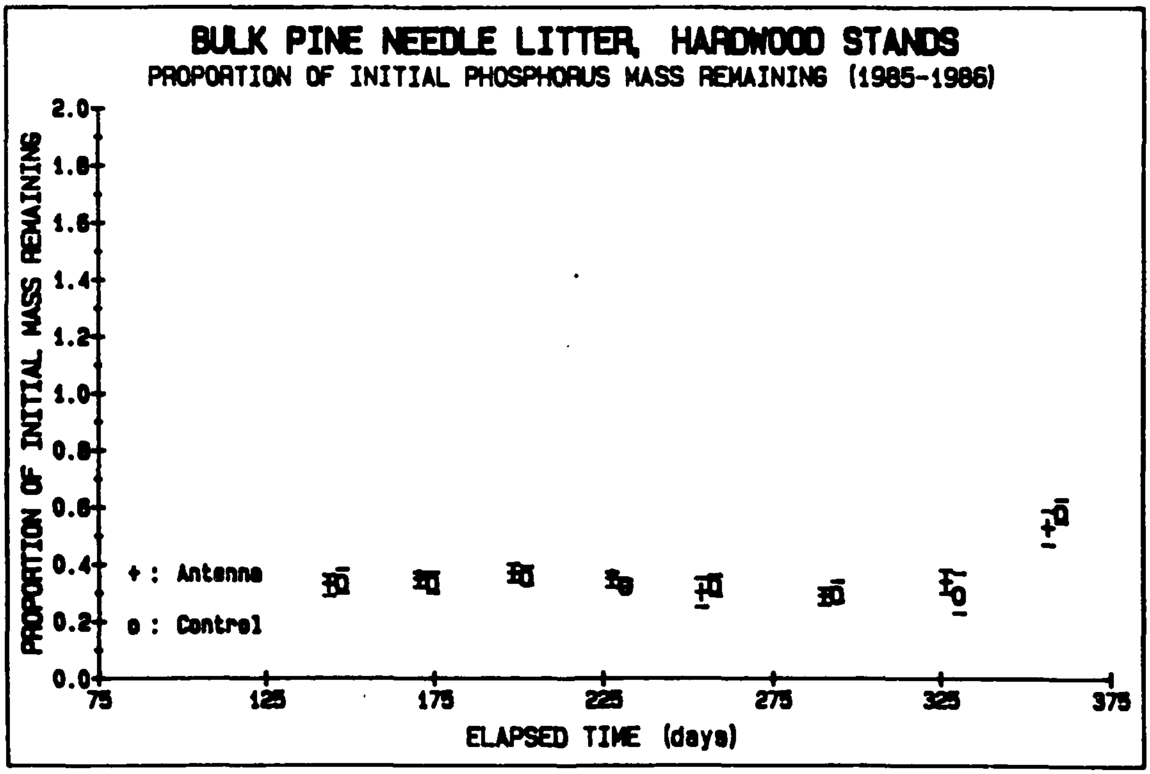
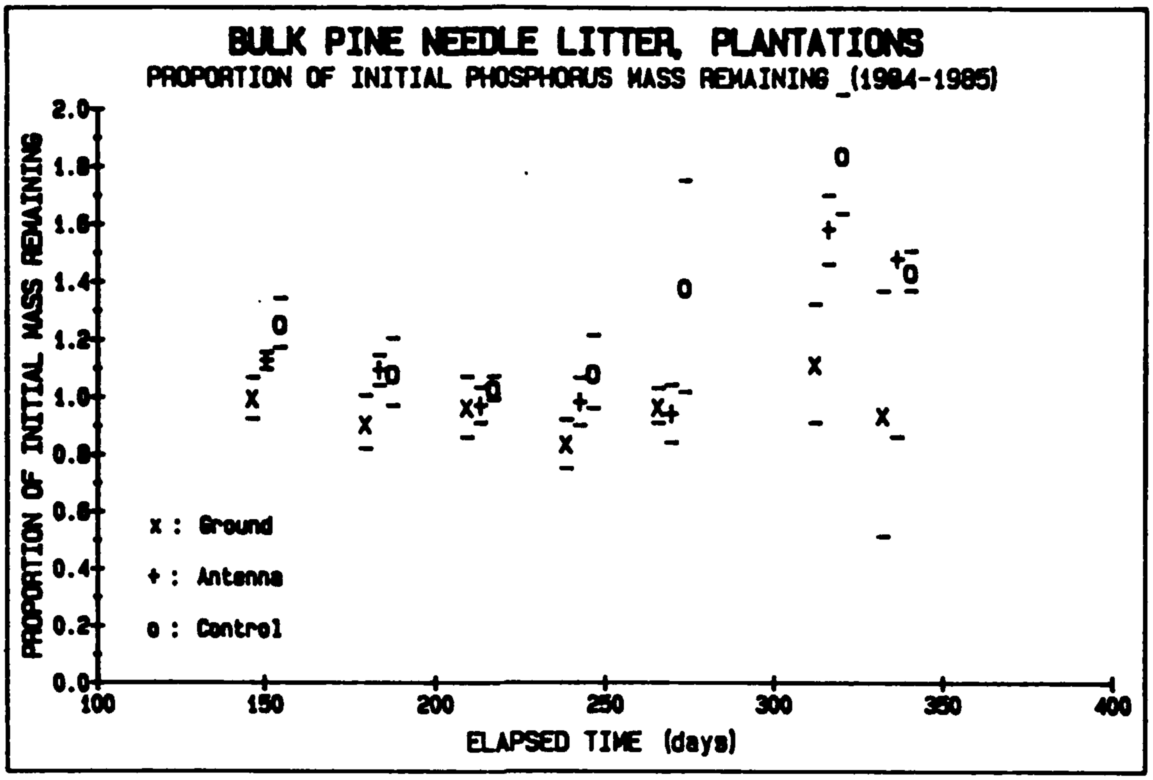

BULK PINE NEEDLE LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

FIGURE 81.


BULK PINE NEEDLE LITTER, PLANTATIONS
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control

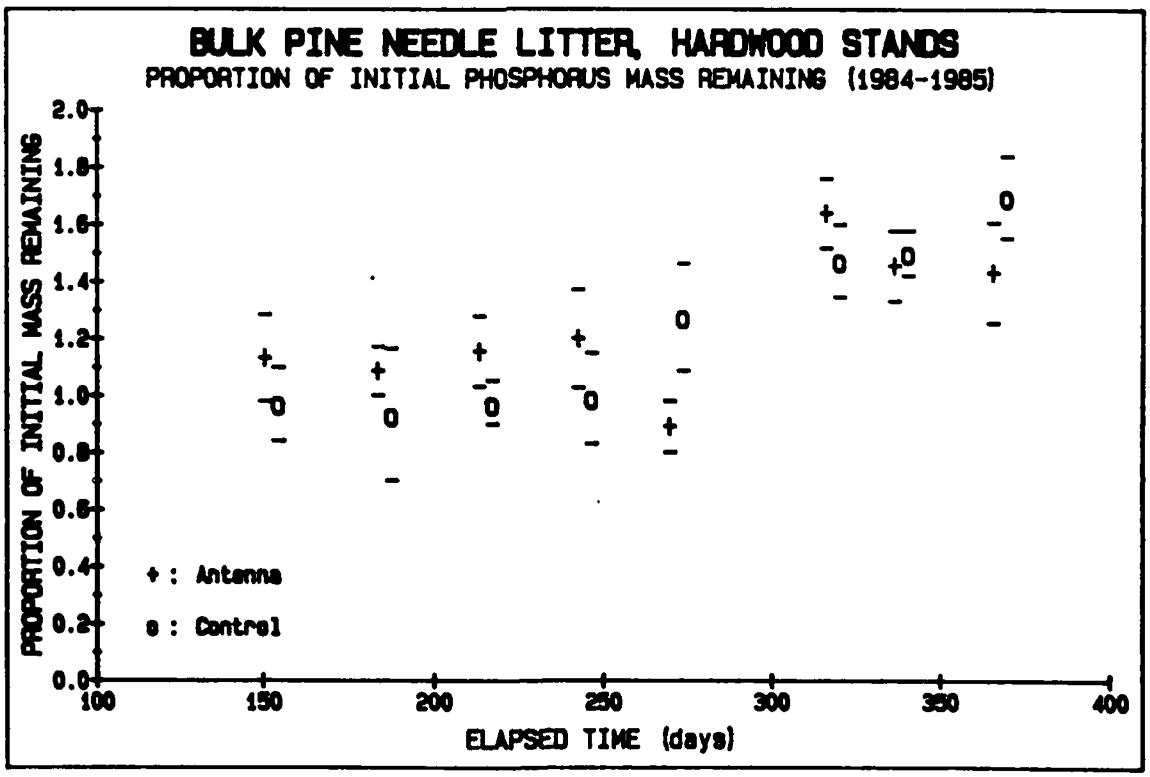

BULK PINE NEEDLE LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
+ : Antenna
o : Control

FIGURE 82.

FIGURE 83.

BULK PINE LITTER, GROUND PLANTATION

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING

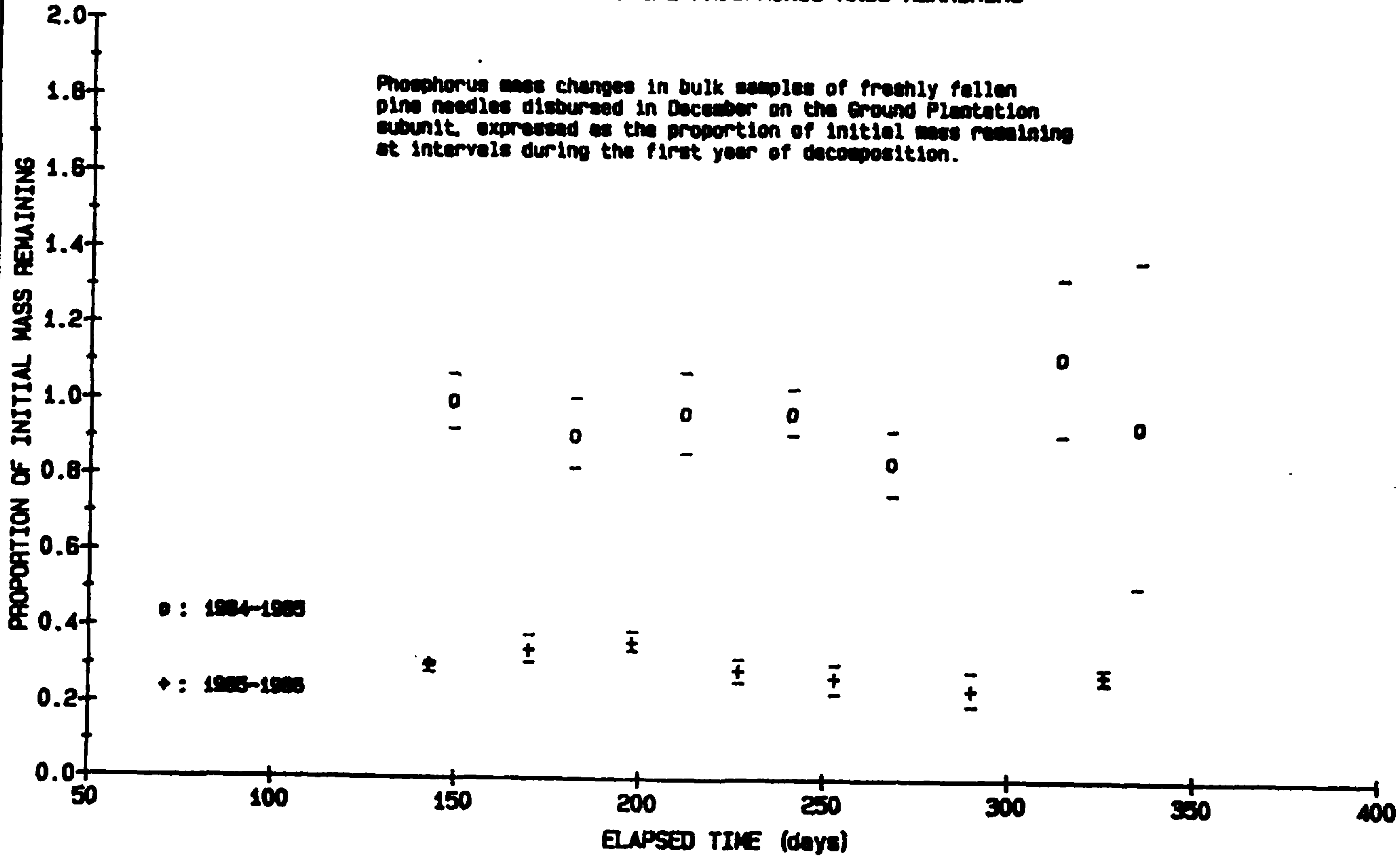


FIGURE 84.

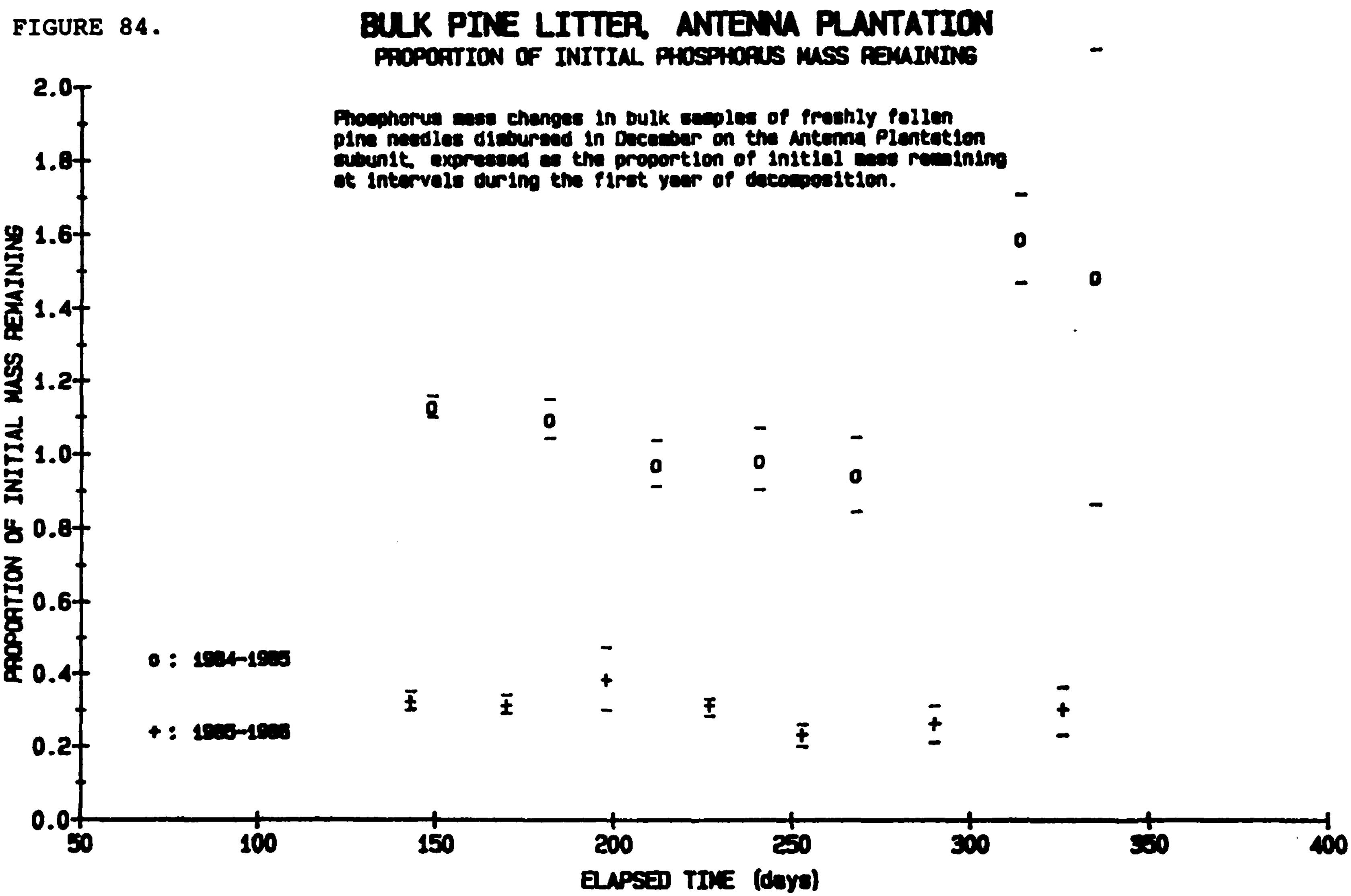

BULK PINE LITTER, ANTENNA PLANTATION
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING
Phosphorus mass changes in bulk samples of freshly fallen pine needles disbursed in December on the Antenna Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
o : 1984-1985
+ : 1985-1986
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 85.

BULK PINE LITTER, CONTROL PLANTATION

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING

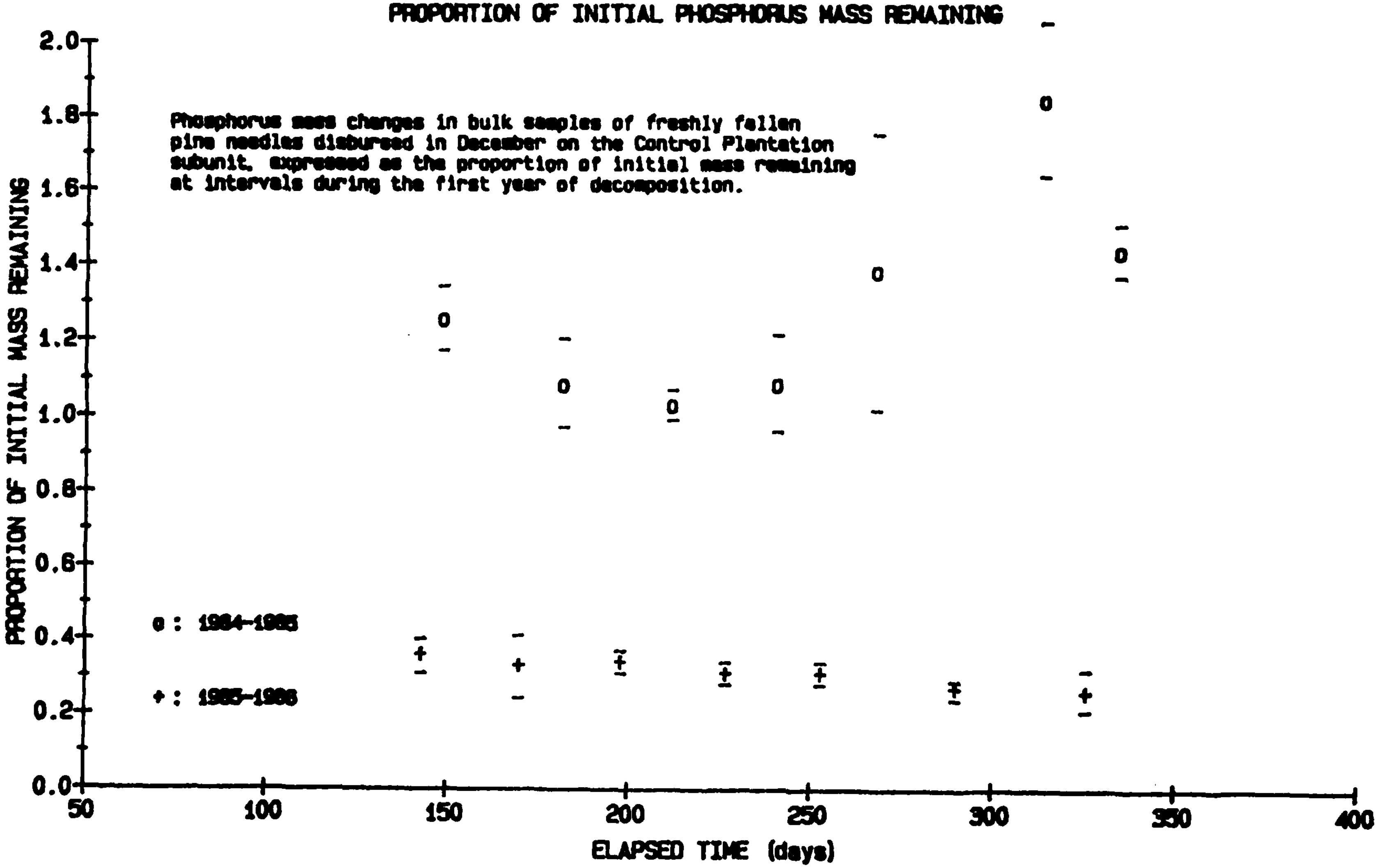


FIGURE 86.

BULK PINE LITTER, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING

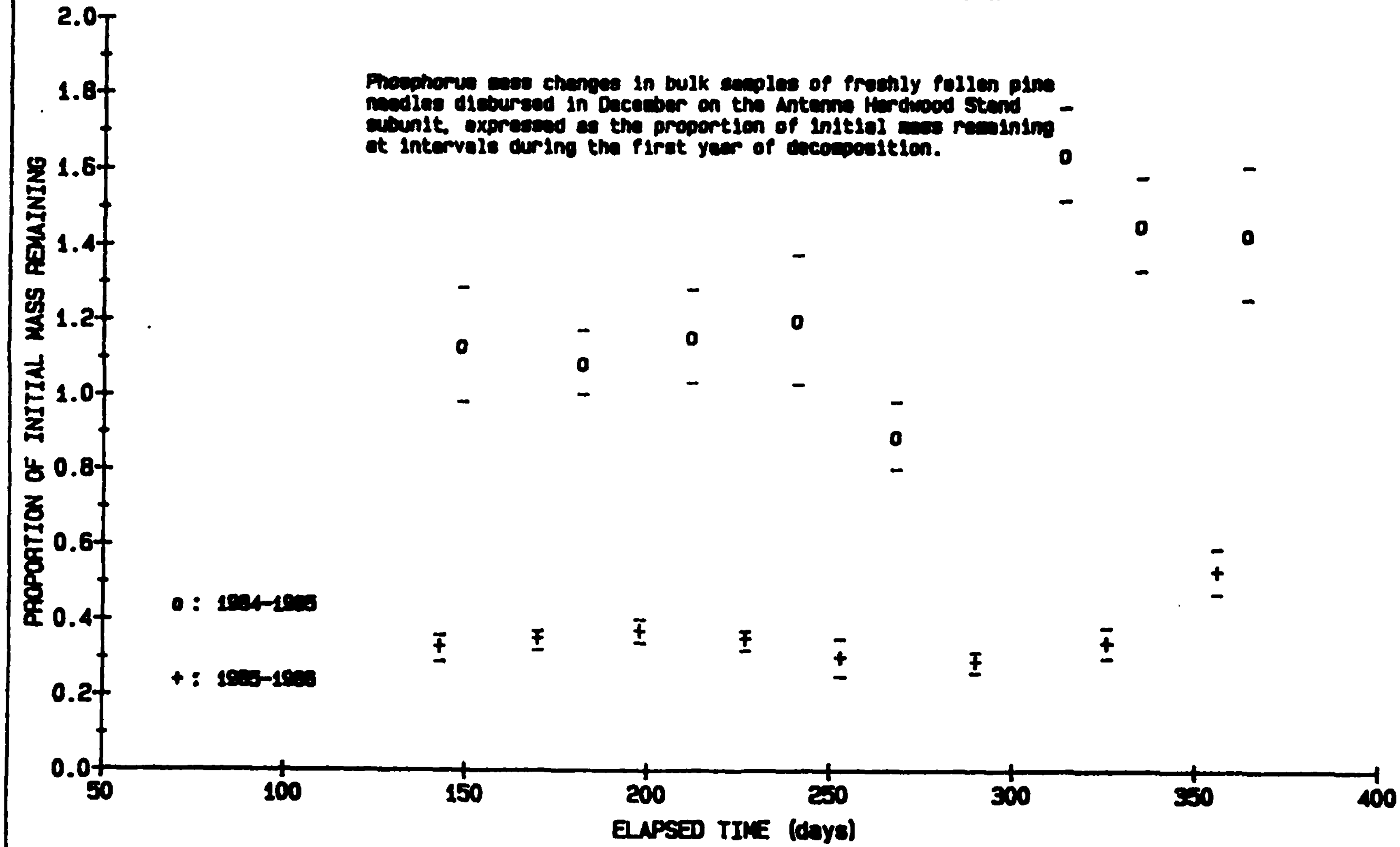
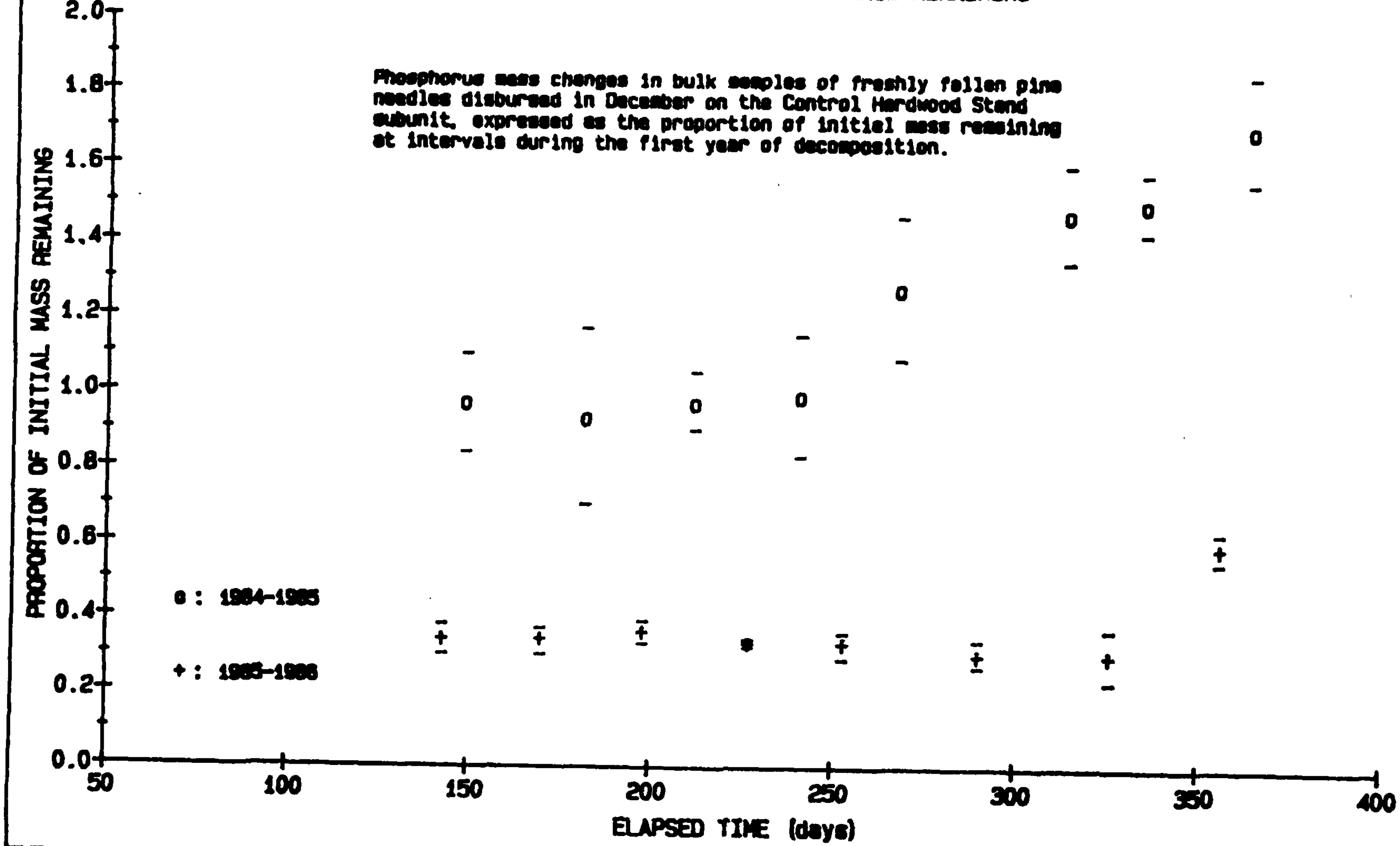
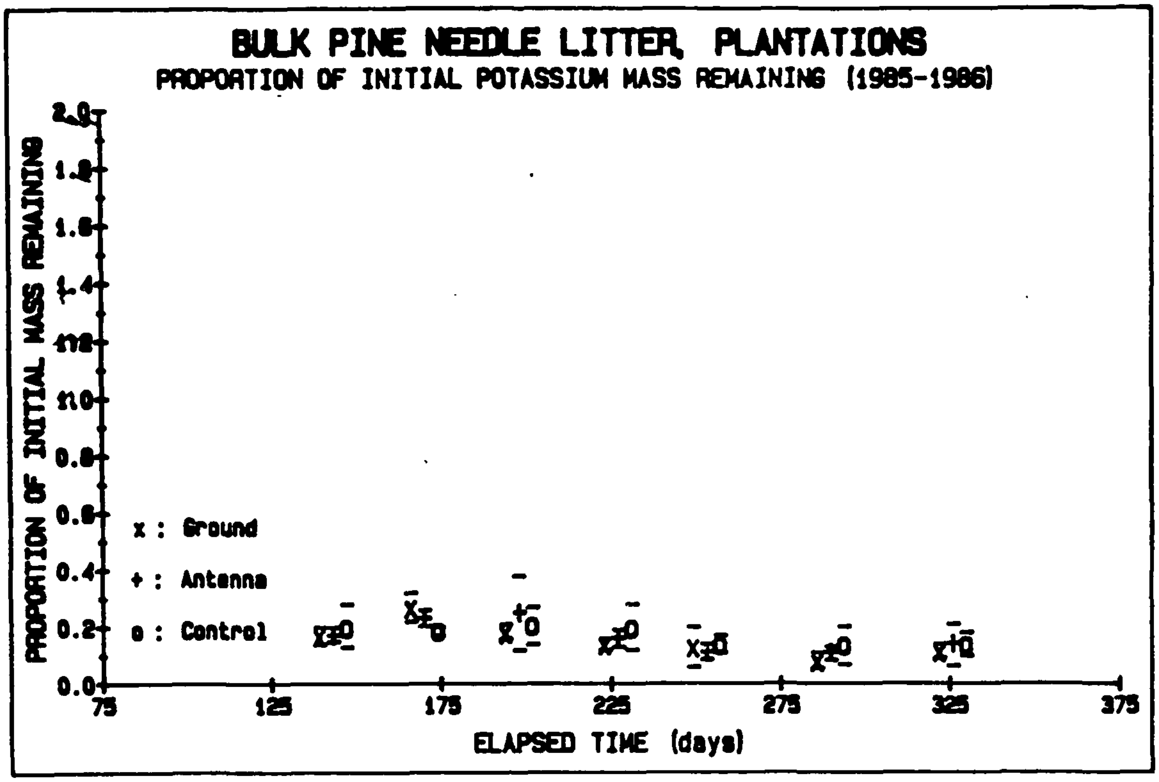


FIGURE 87.

BULK PINE LITTER, CONTROL HARDWOOD STAND

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING




BULK PINE NEEDLE LITTER, PLANTATIONS
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
x : Ground
+ : Antenna
o : Control
ELAPSED TIME (days)

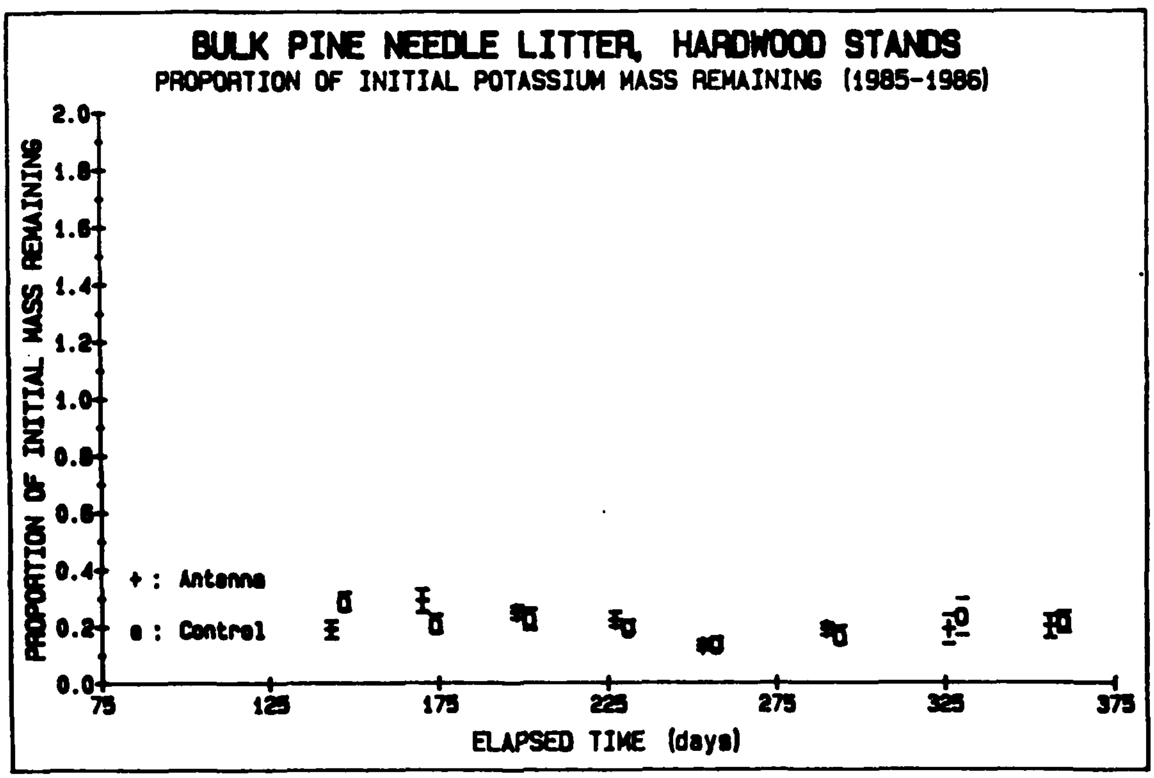
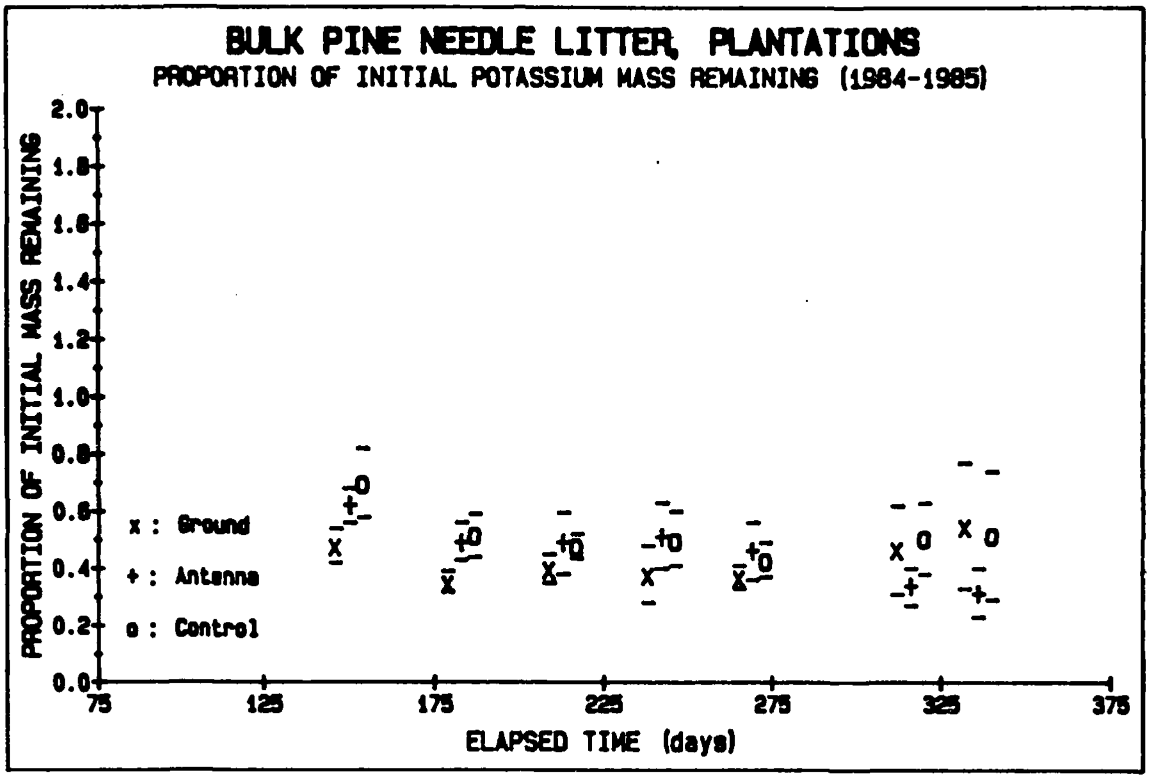

BULK PINE NEEDLE LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
+ : Antenna
o : Control
ELAPSED TIME (days)

FIGURE 88.


BULK PINE NEEDLE LITTER, PLANTATIONS
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

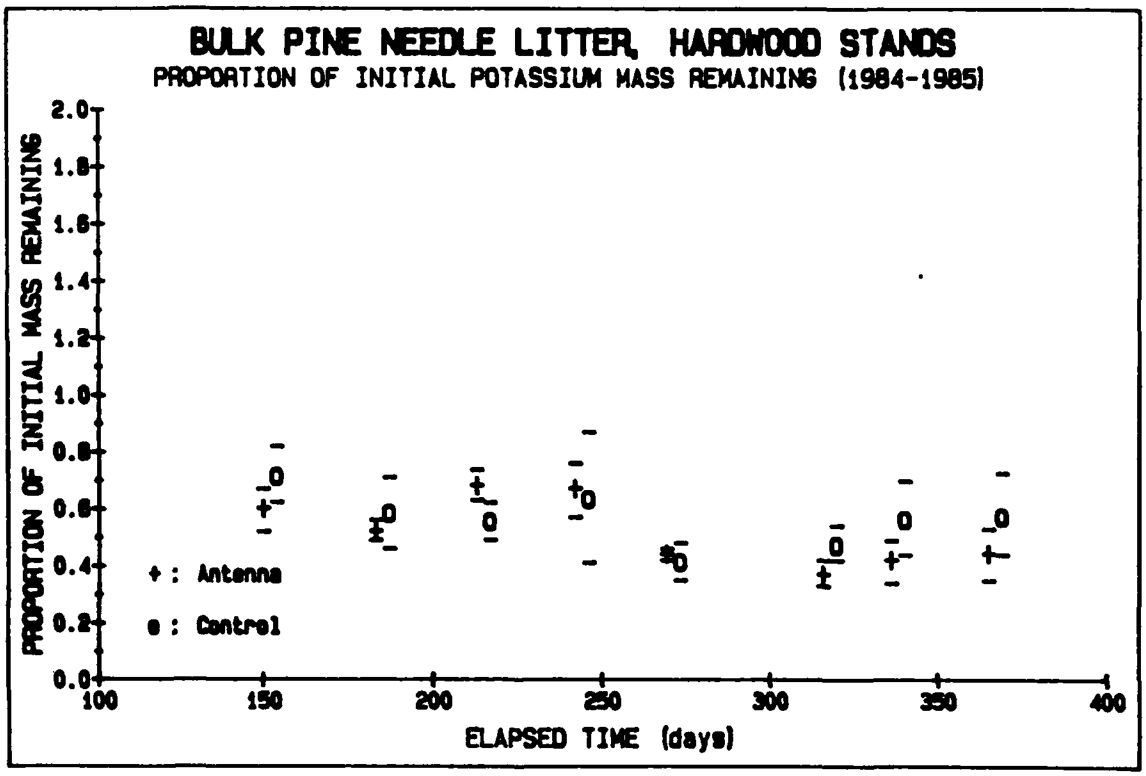

BULK PINE NEEDLE LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 89.

FIGURE 90.

BULK PINE LITTER, GROUND PLANTATION

PROPORTION OF INITIAL POTASSIUM MASS REMAINING

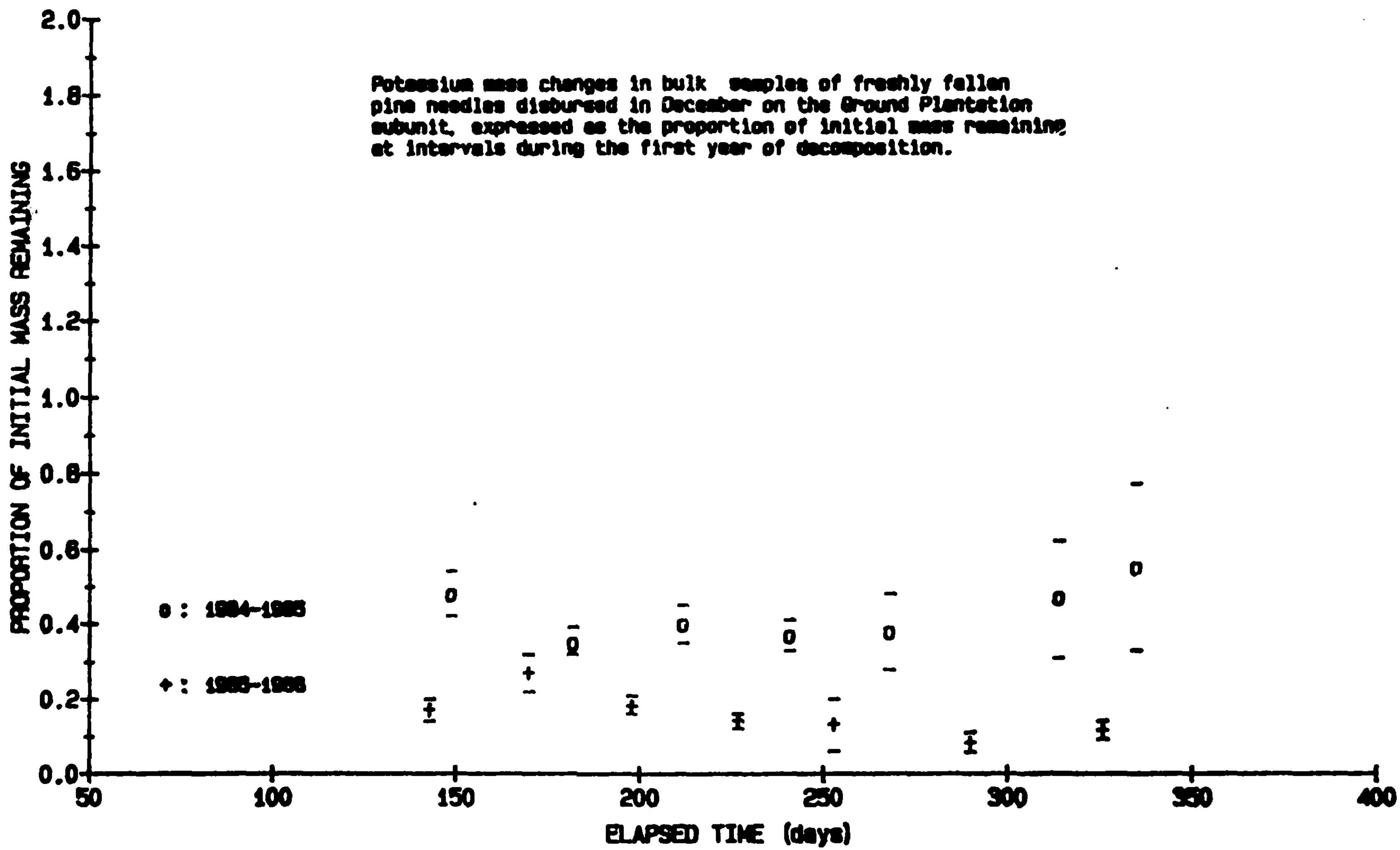


FIGURE 91.

BULK PINE LITTER, ANTENNA PLANTATION
PROPORTION OF INITIAL POTASSIUM MASS REMAINING

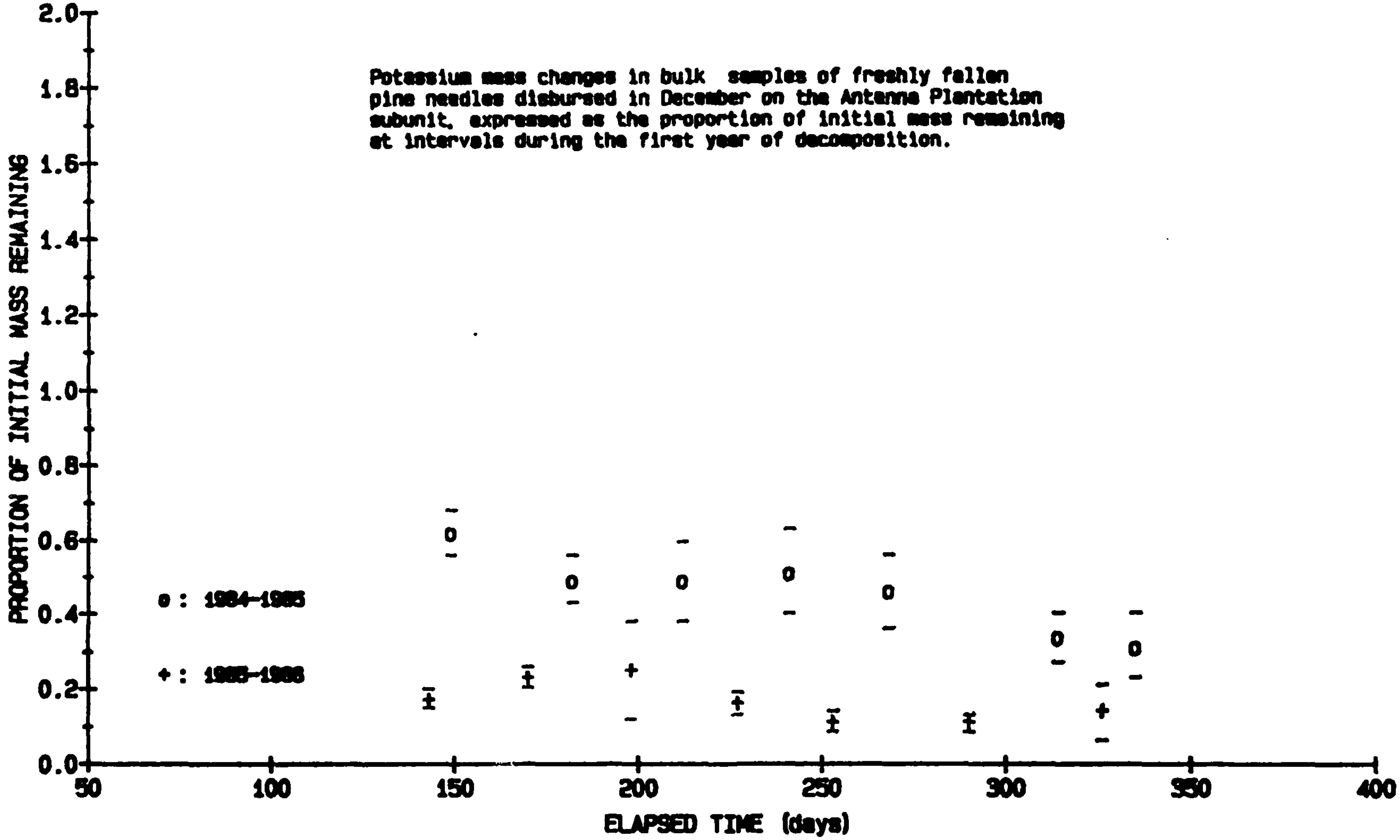


FIGURE 92.

BULK PINE LITTER, CONTROL PLANTATION

PROPORTION OF INITIAL POTASSIUM MASS REMAINING

Potassium mass changes in bulk samples of freshly fallen pine needles disbursed in December on the Control Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

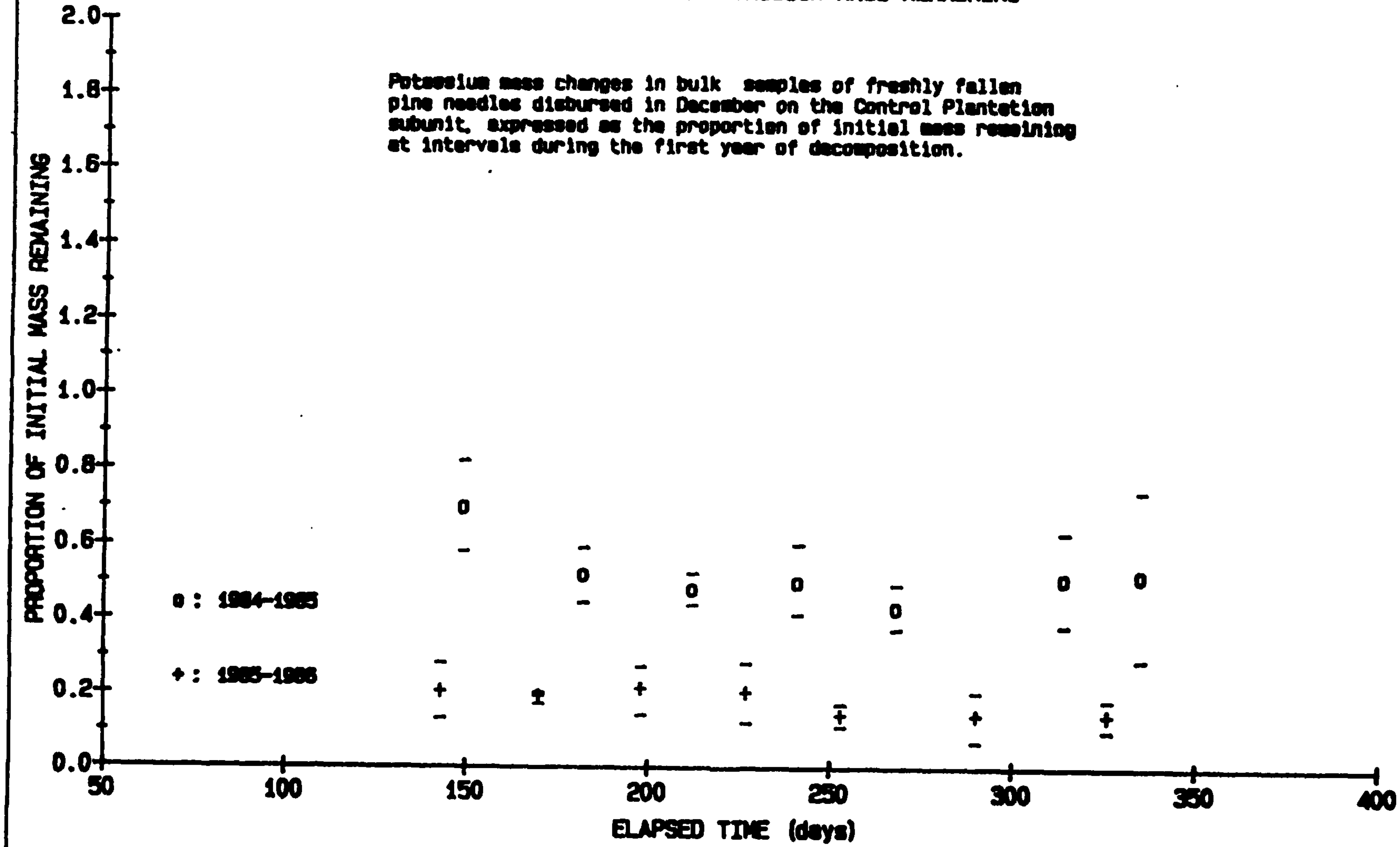


FIGURE 93.

BULK PINE LITTER, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL POTASSIUM MASS REMAINING

Potassium mass changes in bulk samples of freshly fallen pine needles disbursed in December on the Antenna Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

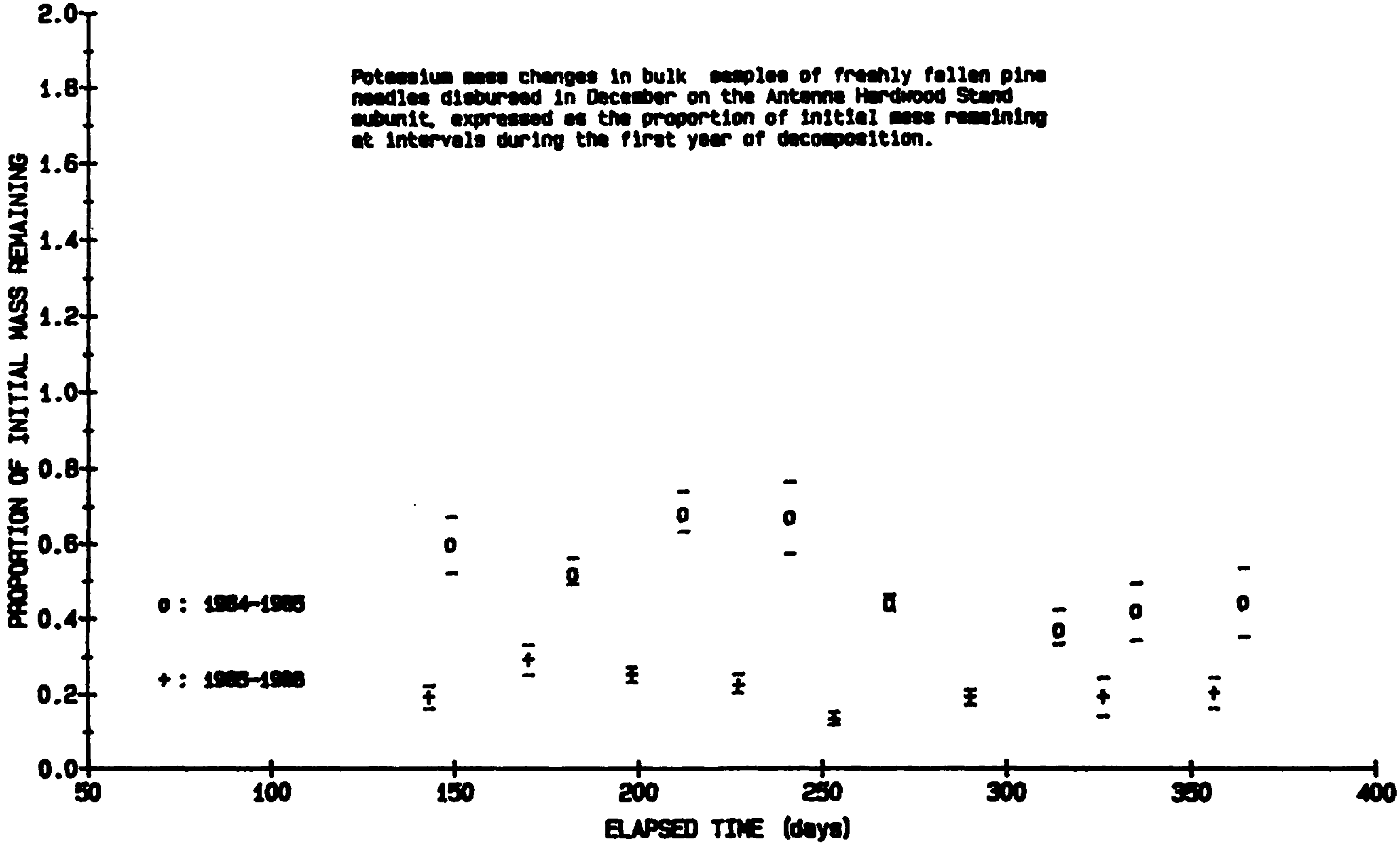
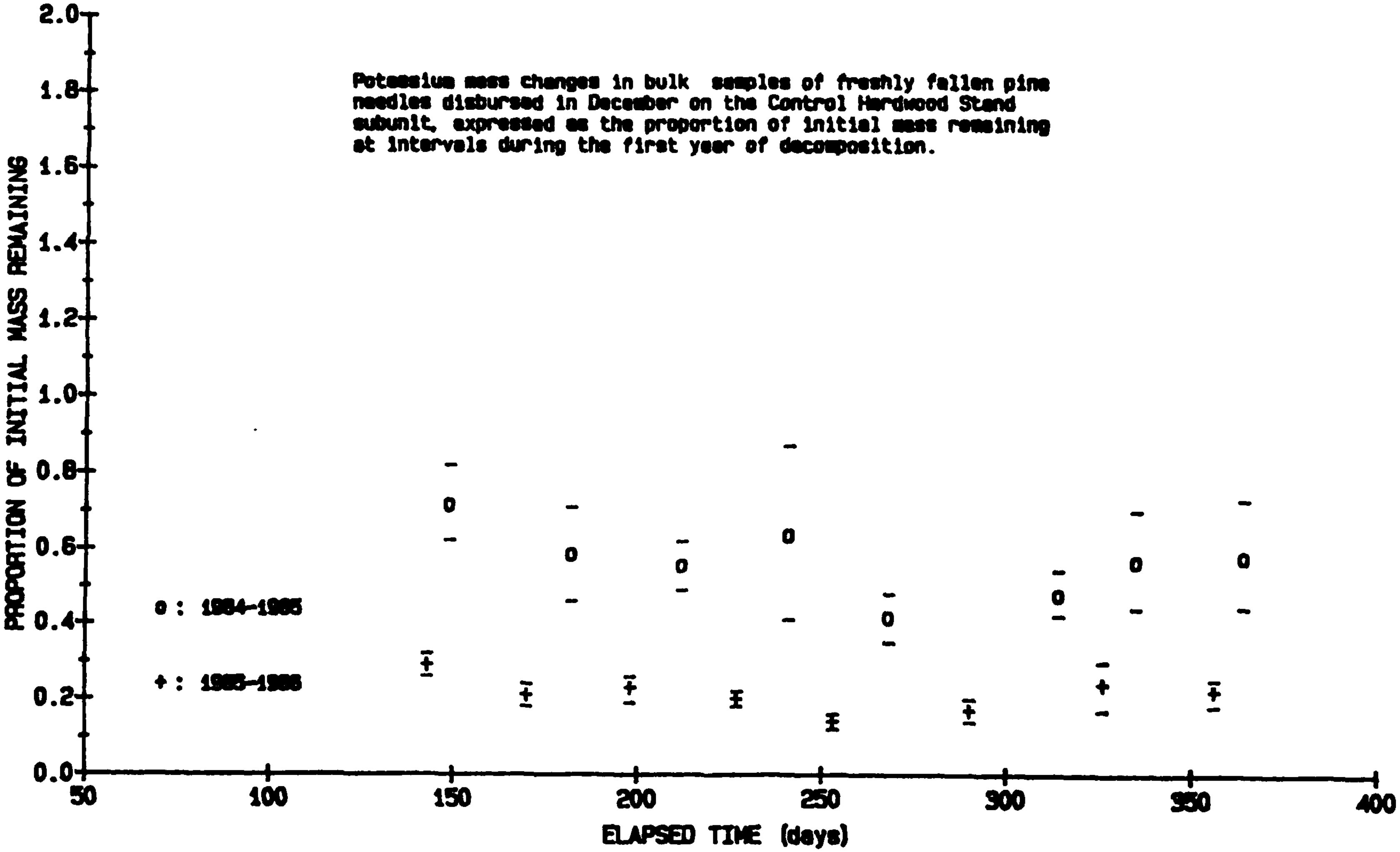


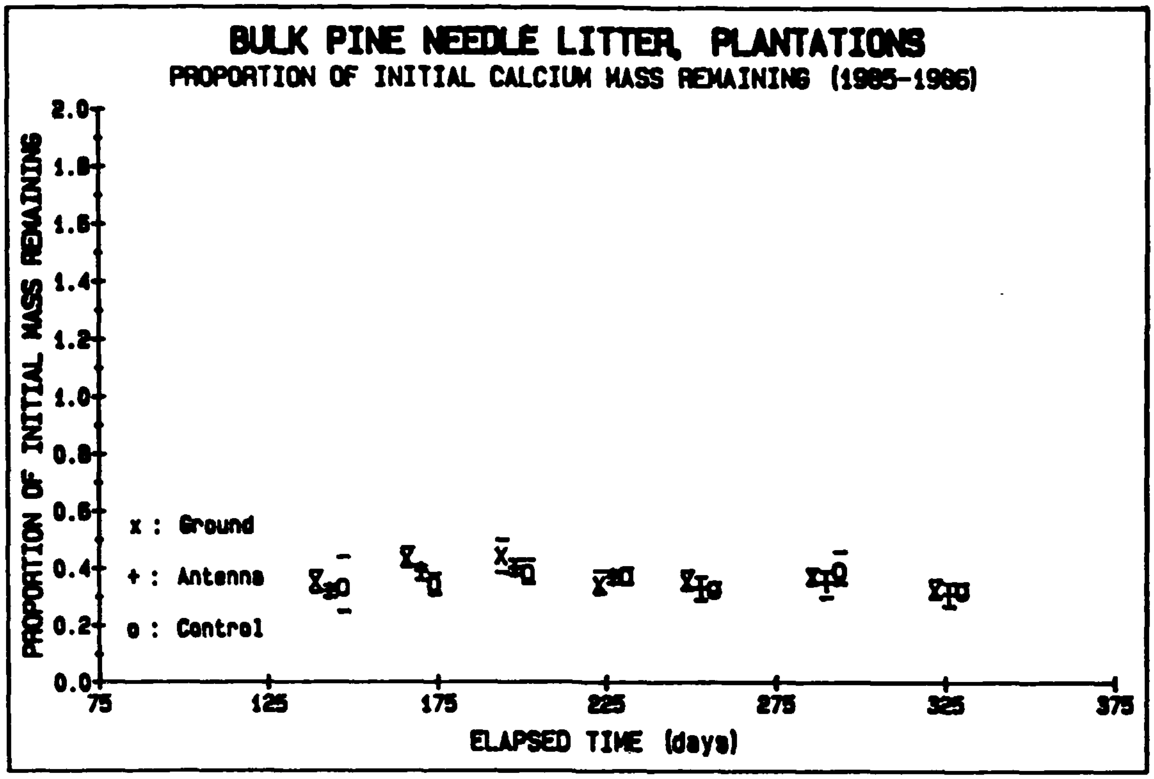
FIGURE 94.

BULK PINE LITTER, CONTROL HARDWOOD STAND

PROPORTION OF INITIAL POTASSIUM MASS REMAINING

Potassium mass changes in bulk samples of freshly fallen pine needles disbursed in December on the Control Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.




BULK PINE NEEDLE LITTER, PLANTATIONS
PROPORTION OF INITIAL CALCIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

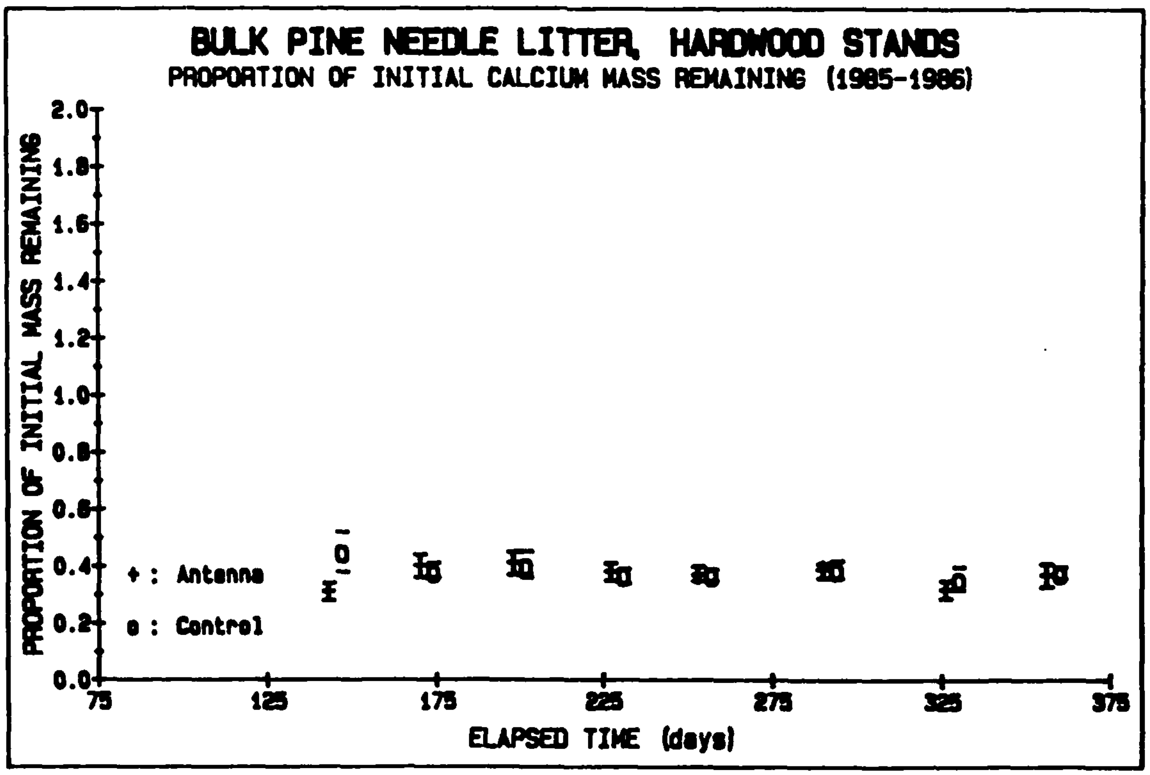
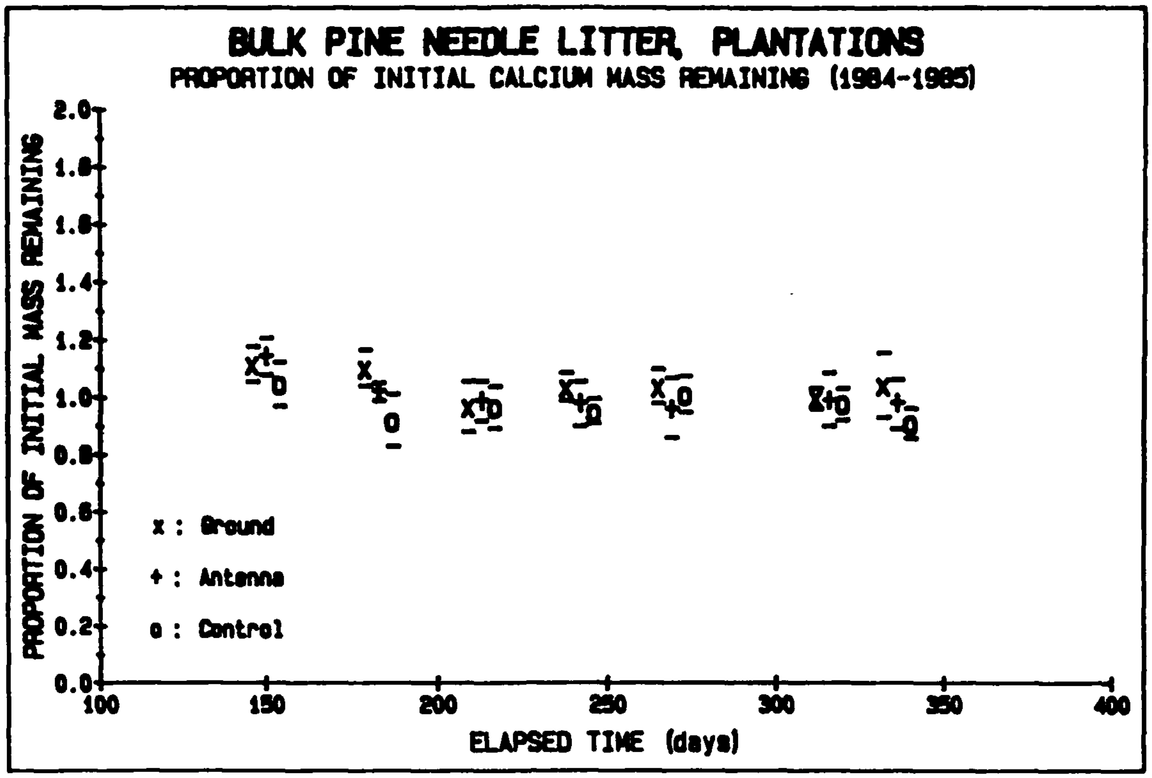

BULK PINE NEEDLE LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL CALCIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

FIGURE 95.


BULK PINE NEEDLE LITTER, PLANTATIONS
PROPORTION OF INITIAL CALCIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

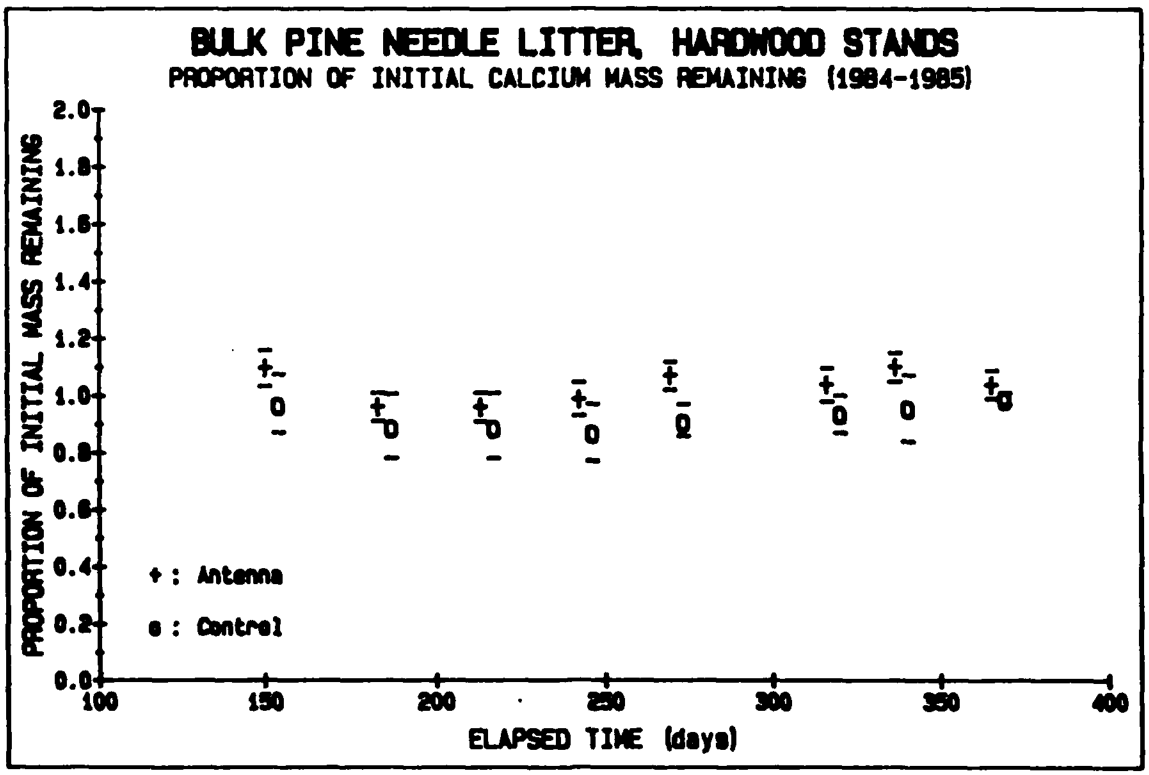

BULK PINE NEEDLE LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL CALCIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 96.

FIGURE 97.

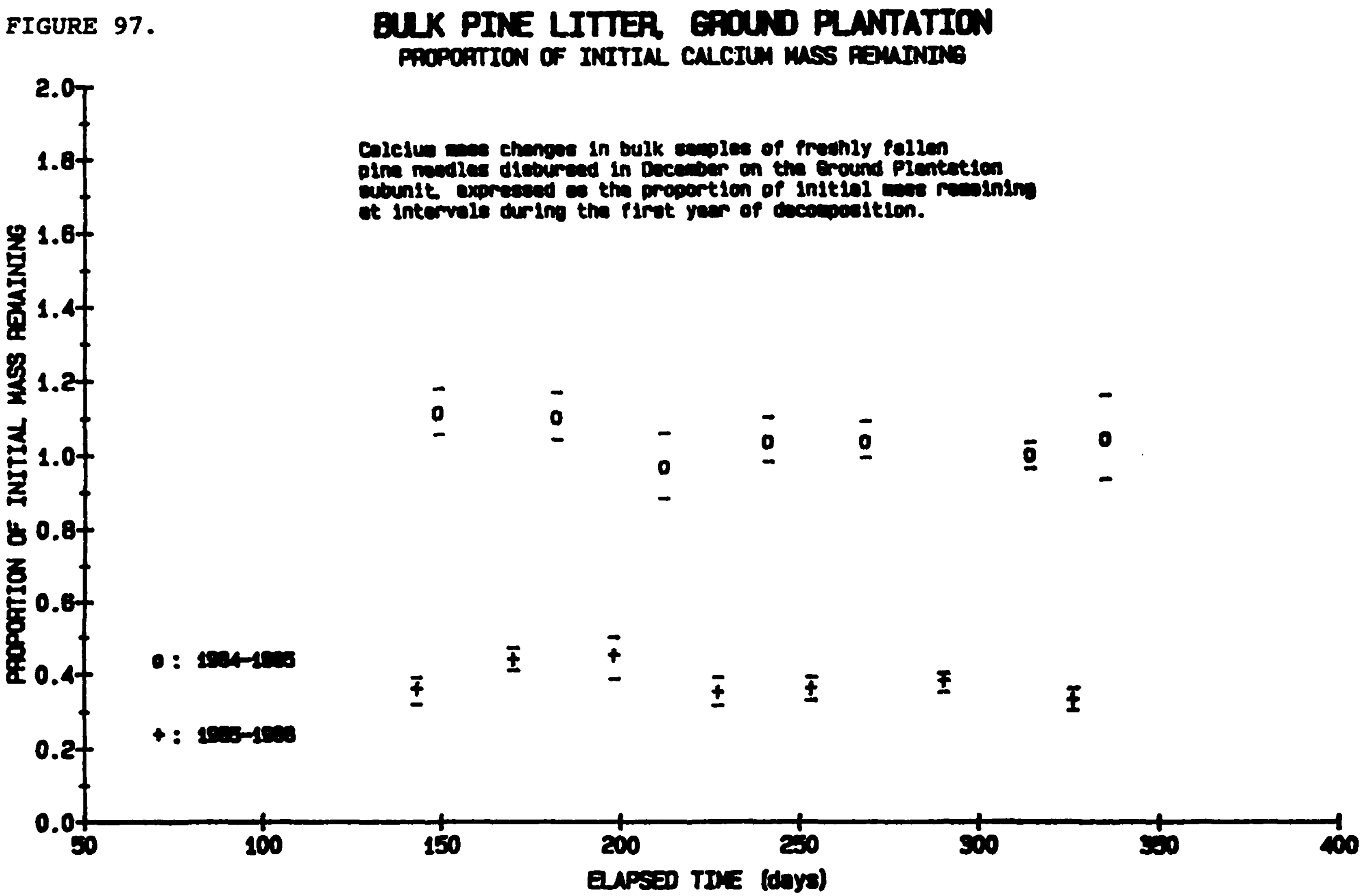

BULK PINE LITTER, GROUND PLANTATION
PROPORTION OF INITIAL CALCIUM MASS REMAINING
Calcium mass changes in bulk samples of freshly fallen pine needles disbursed in December on the Ground Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
o : 1984-1985
+ : 1985-1986
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 98.

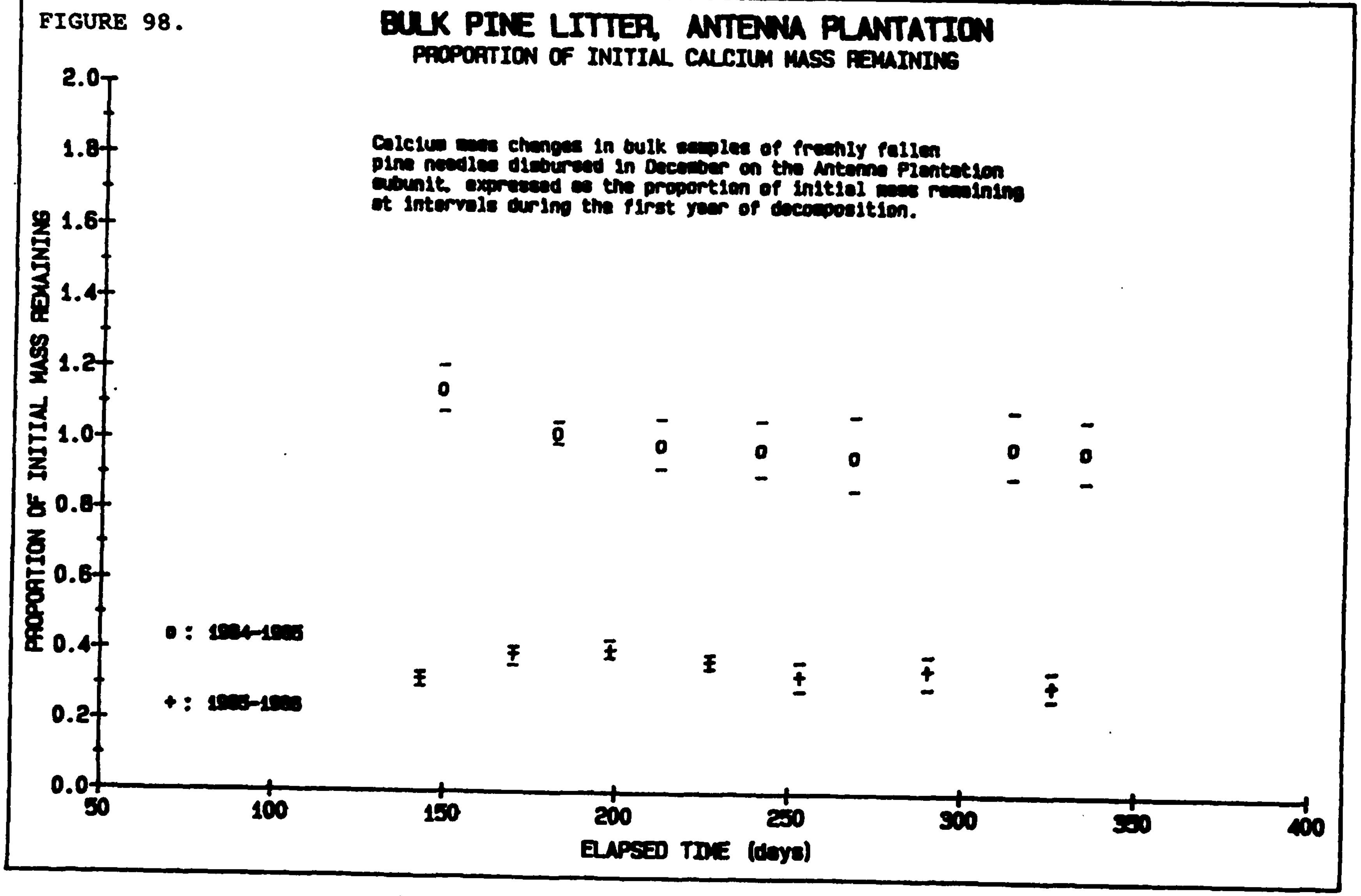

BULK PINE LITTER, ANTENNA PLANTATION
PROPORTION OF INITIAL CALCIUM MASS REMAINING
Calcium mass changes in bulk samples of freshly fallen pine needles disbursed in December on the Antenna Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
o : 1984-1985
+ : 1985-1986
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 99.

BULK PINE LITTER, CONTROL PLANTATION

PROPORTION OF INITIAL CALCIUM MASS REMAINING

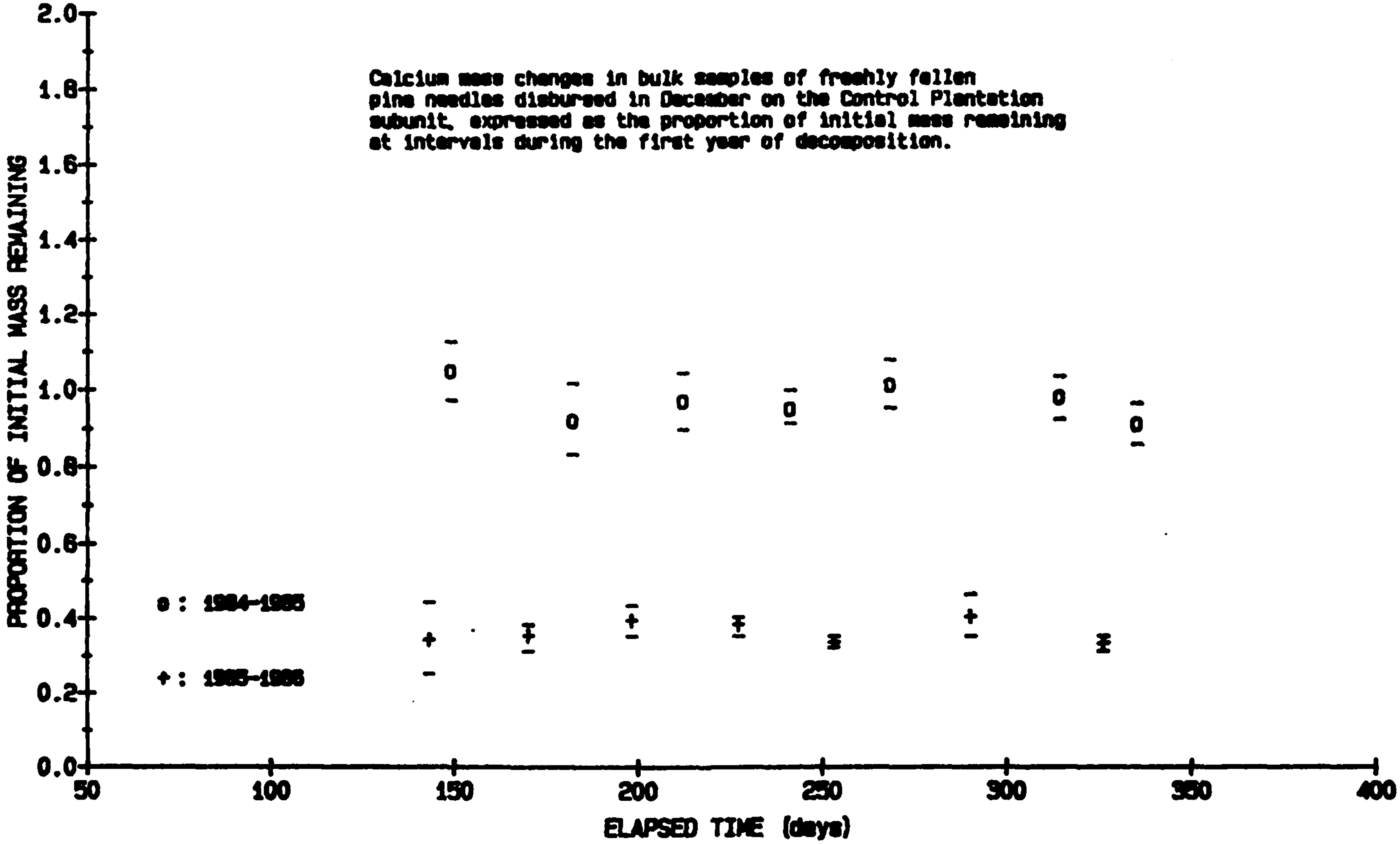


FIGURE 100.

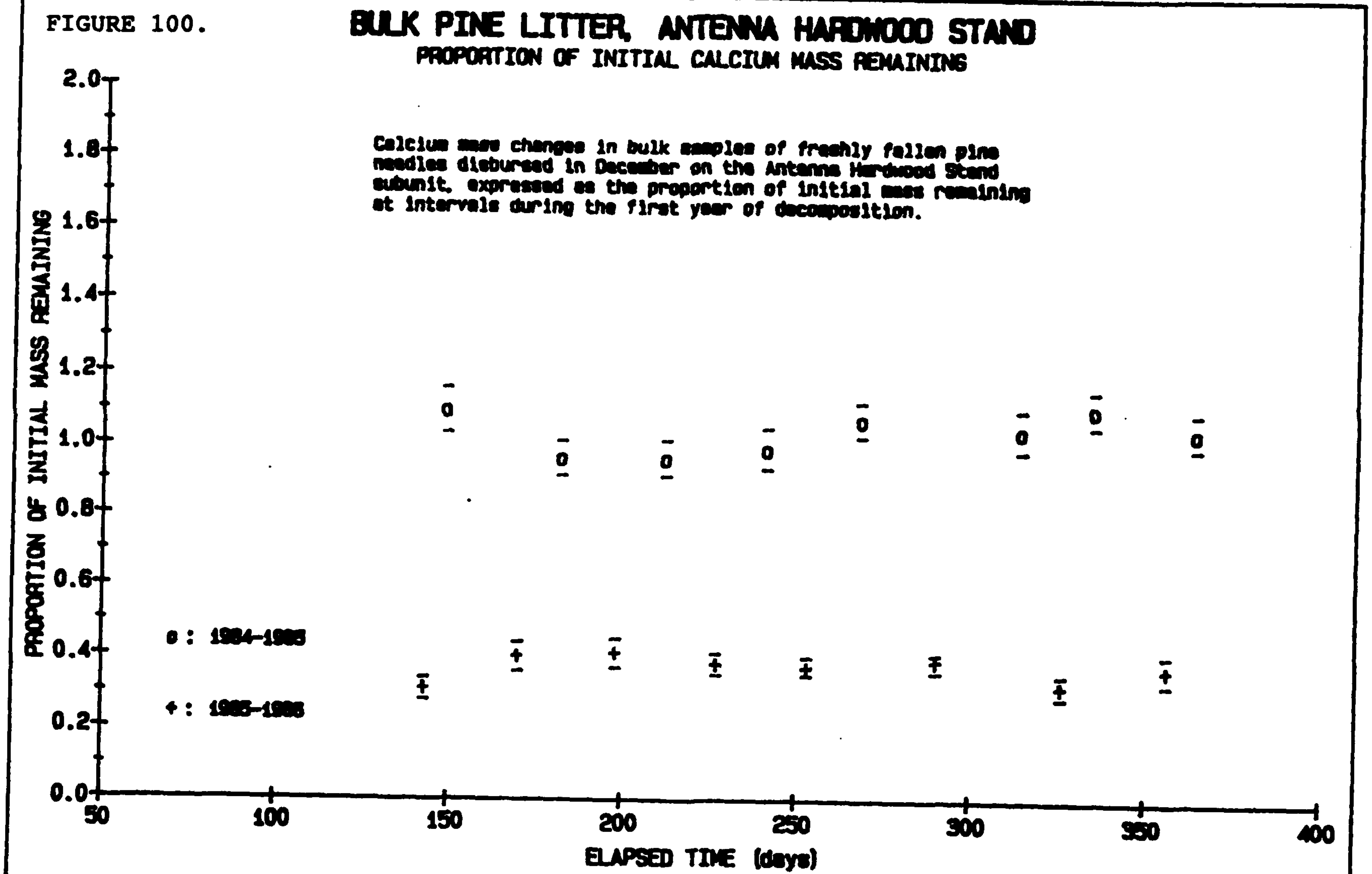
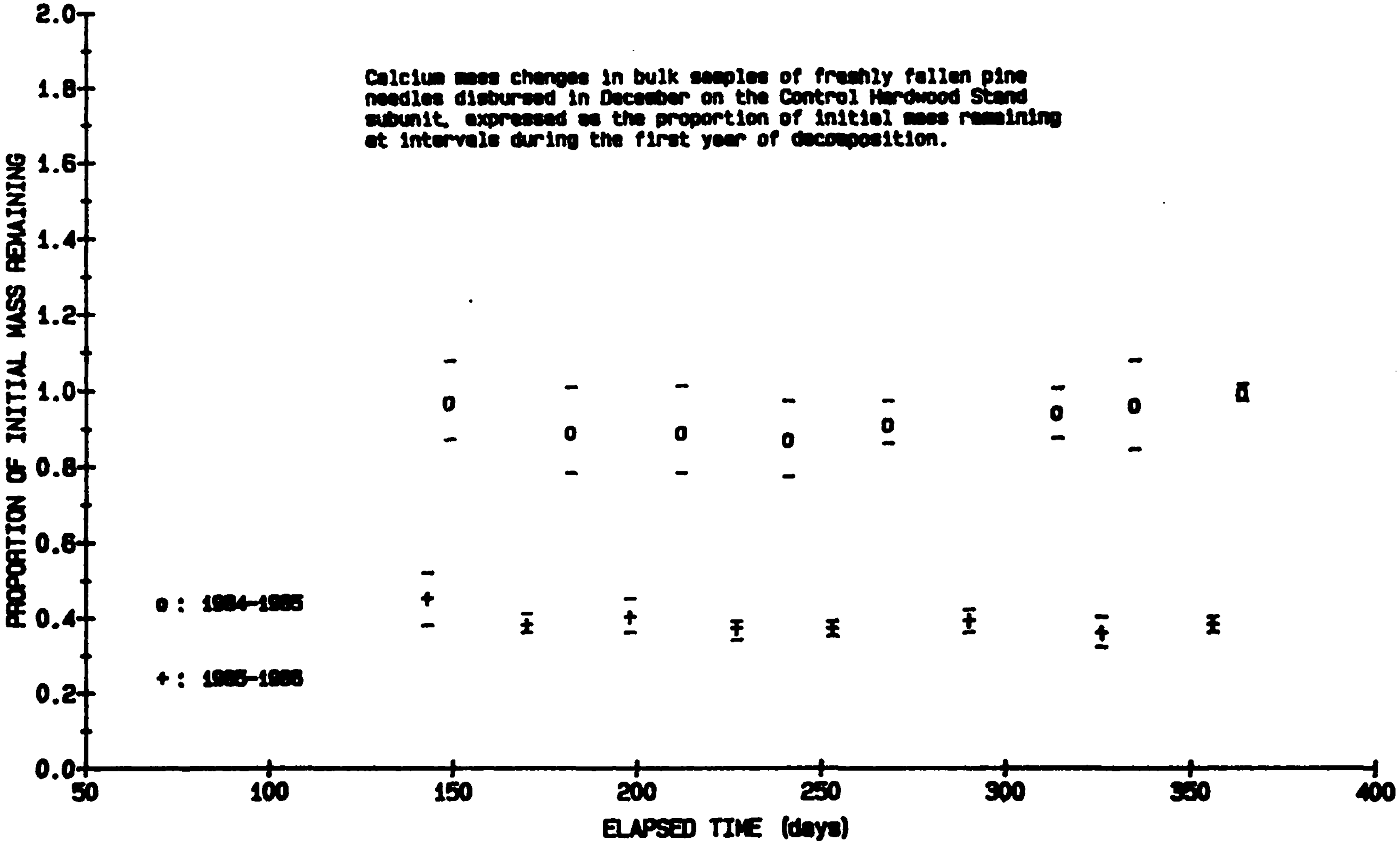
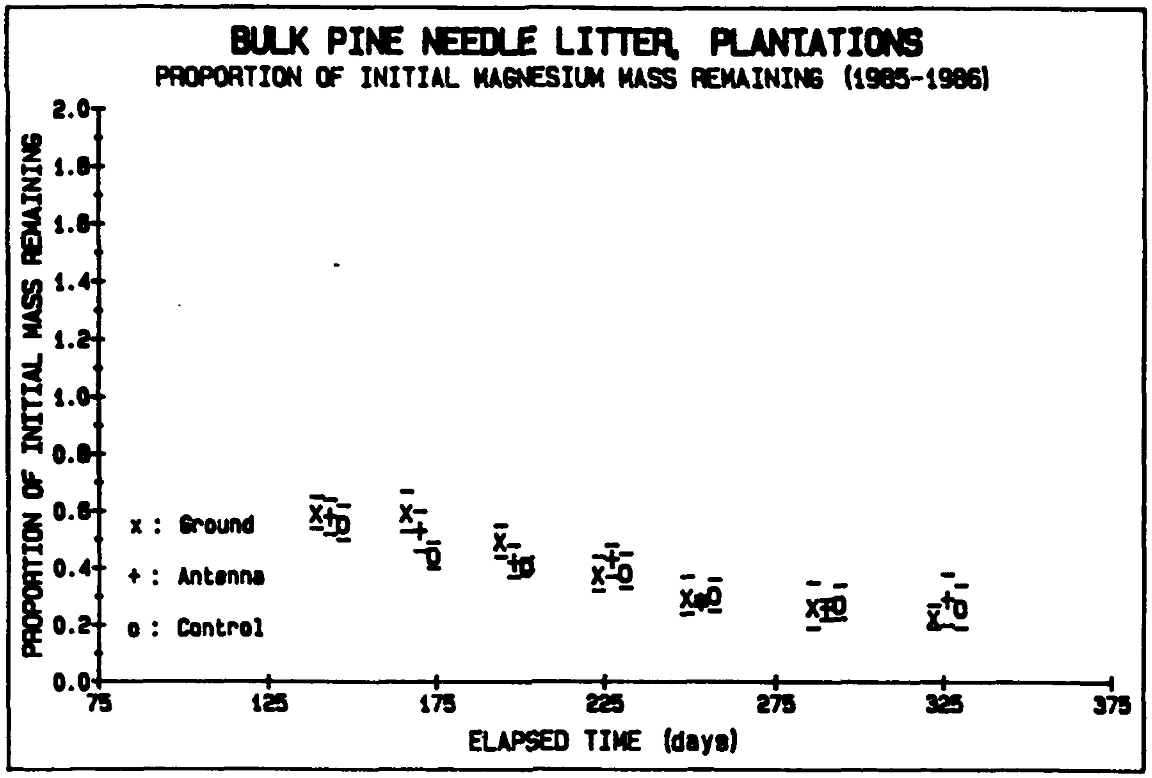

BULK PINE LITTER, ANTENNA HARDWOOD STAND
PROPORTION OF INITIAL CALCIUM MASS REMAINING
Calcium mass changes in bulk samples of freshly fallen pine needles disbursed in December on the Antenna Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
o : 1984-1985
+ : 1985-1986
PROPORTION OF INITIAL MASS REMAINING
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 101.

BULK PINE LITTER, CONTROL HARDWOOD STAND

PROPORTION OF INITIAL CALCIUM MASS REMAINING




BULK PINE NEEDLE LITTER, PLANTATIONS
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

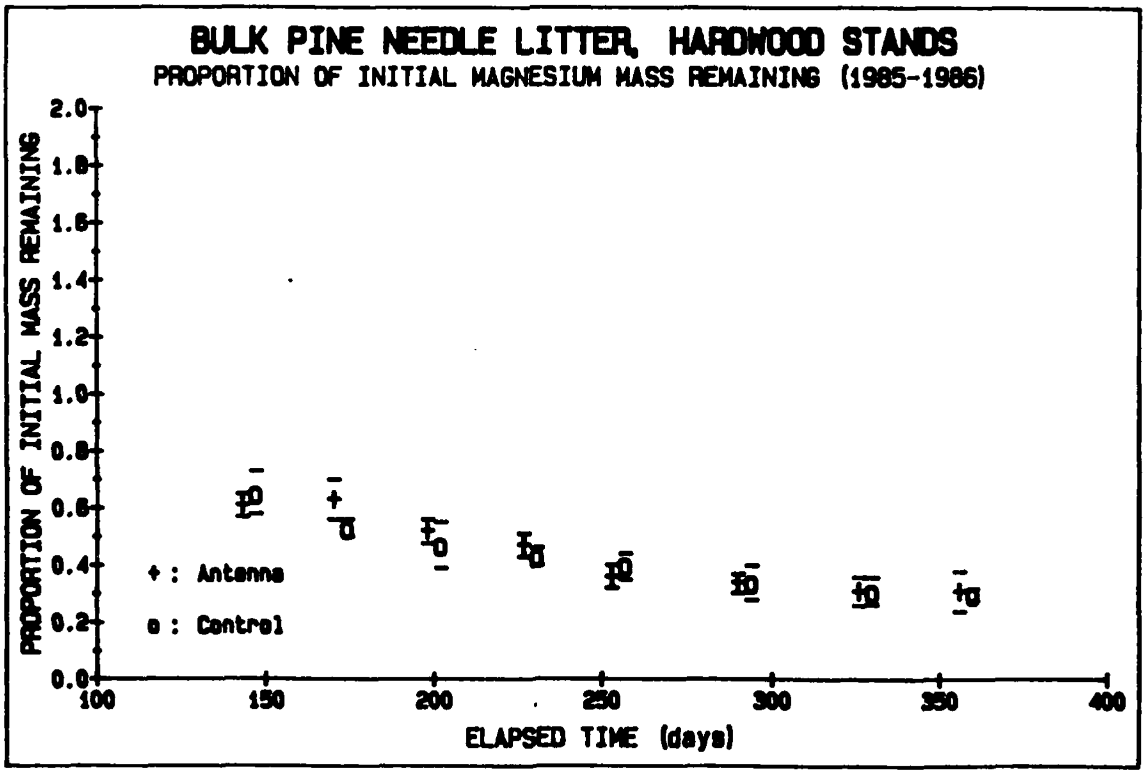
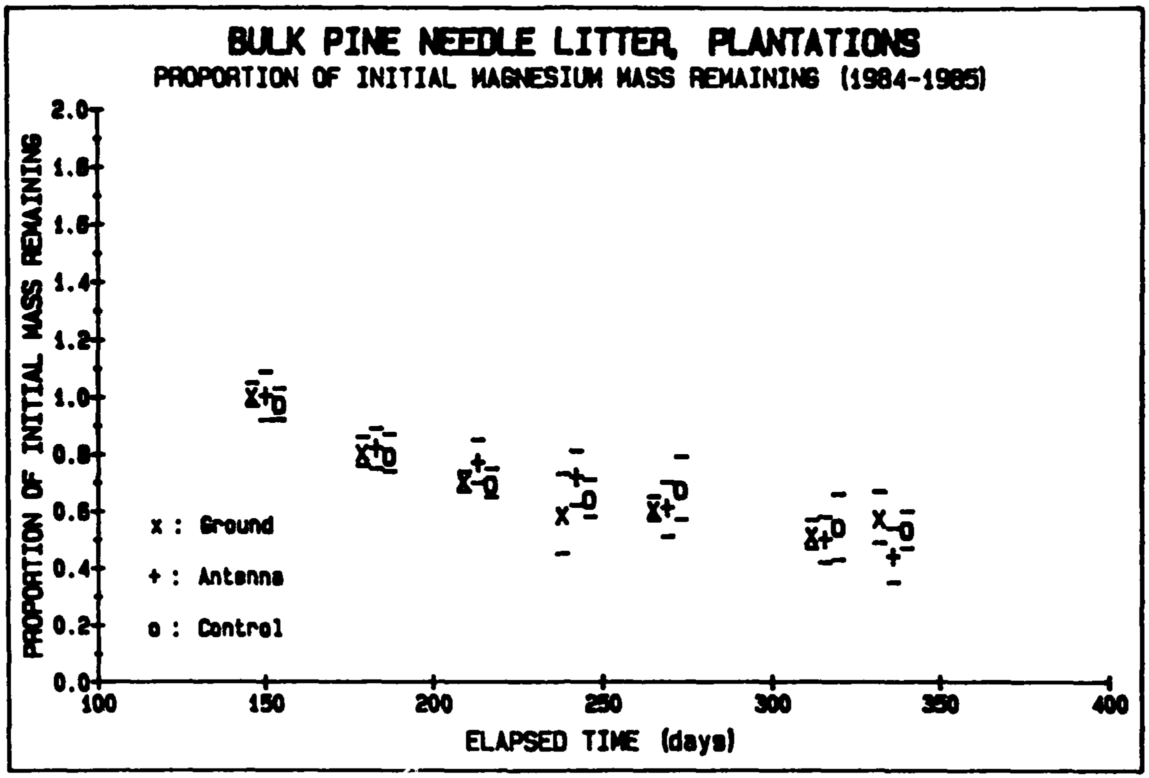

BULK PINE NEEDLE LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 102.


BULK PINE NEEDLE LITTER, PLANTATIONS
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

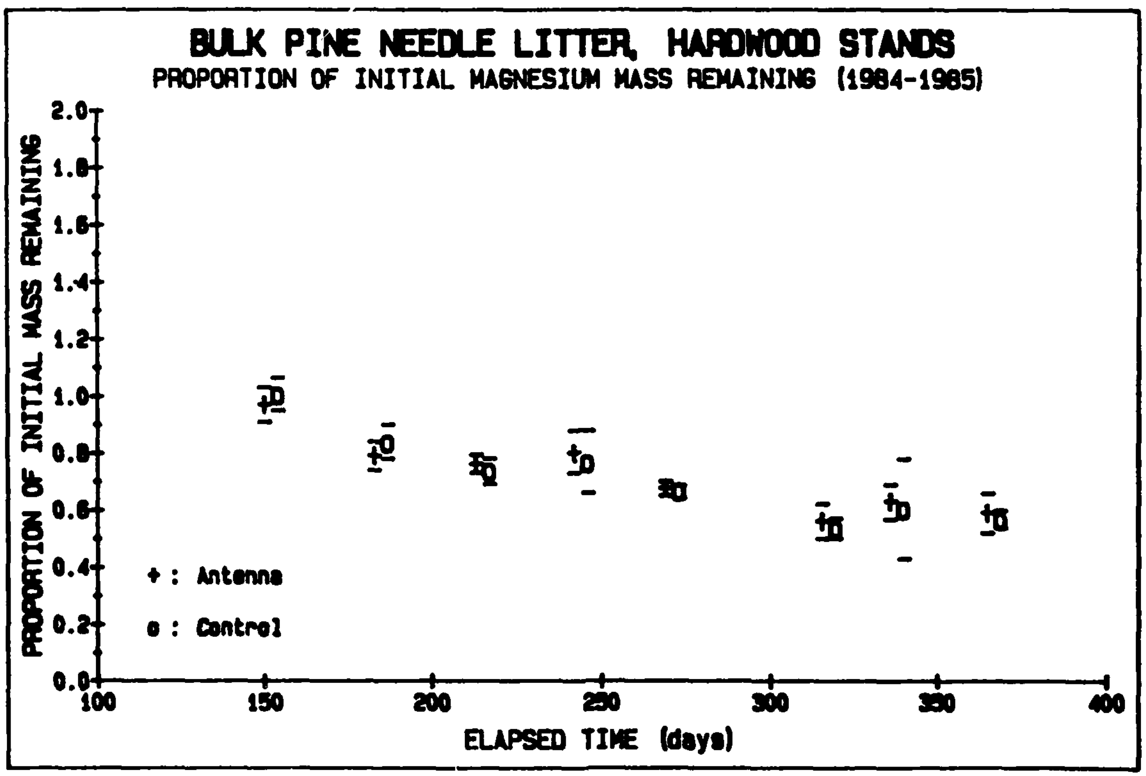

BULK PINE NEEDLE LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 103.

FIGURE 104.

BULK PINE LITTER, GROUND PLANTATION

PROPORTION OF INITIAL MAGNESIUM MASS REMAINING

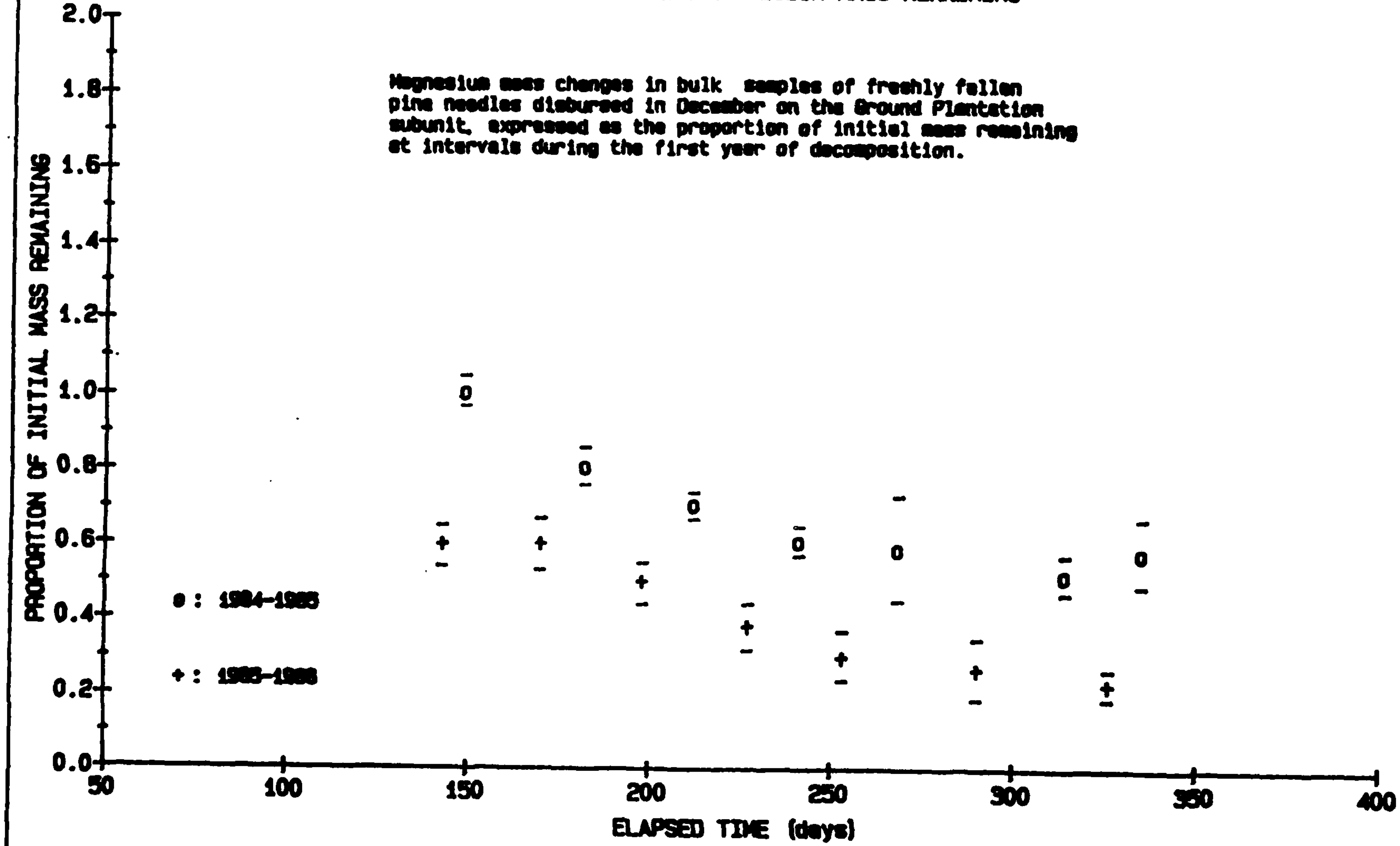


FIGURE 105.

BULK PINE LITTER, ANTENNA PLANTATION

PROPORTION OF INITIAL MAGNESIUM MASS REMAINING

Magnesium mass changes in bulk samples of freshly fallen pine needles disbursed in December on the Antenna Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

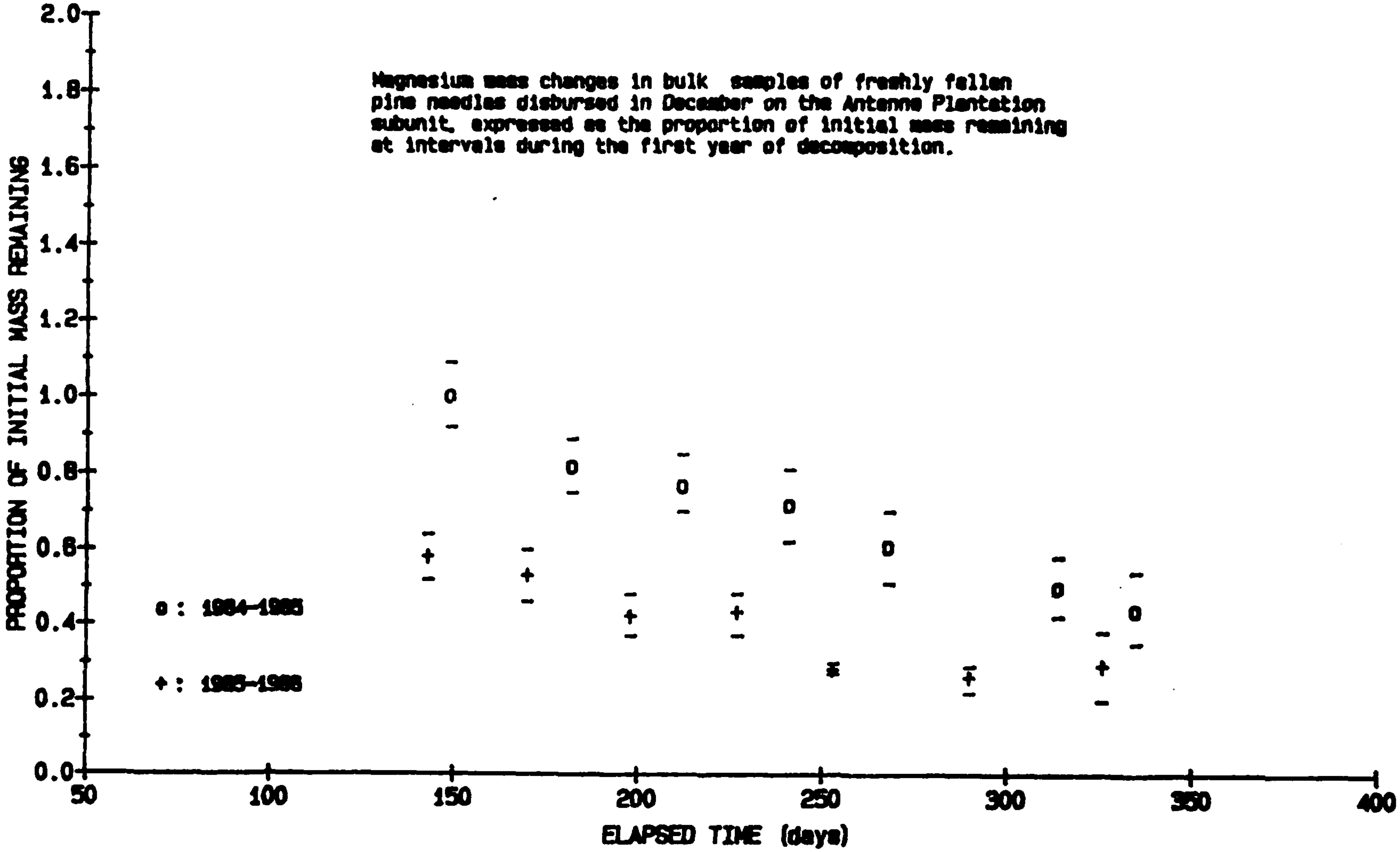


FIGURE 106.

BULK PINE LITTER, CONTROL PLANTATION

PROPORTION OF INITIAL MAGNESIUM MASS REMAINING

Magnesium mass changes in bulk samples of freshly fallen pine needles disbursed in December on the Control Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

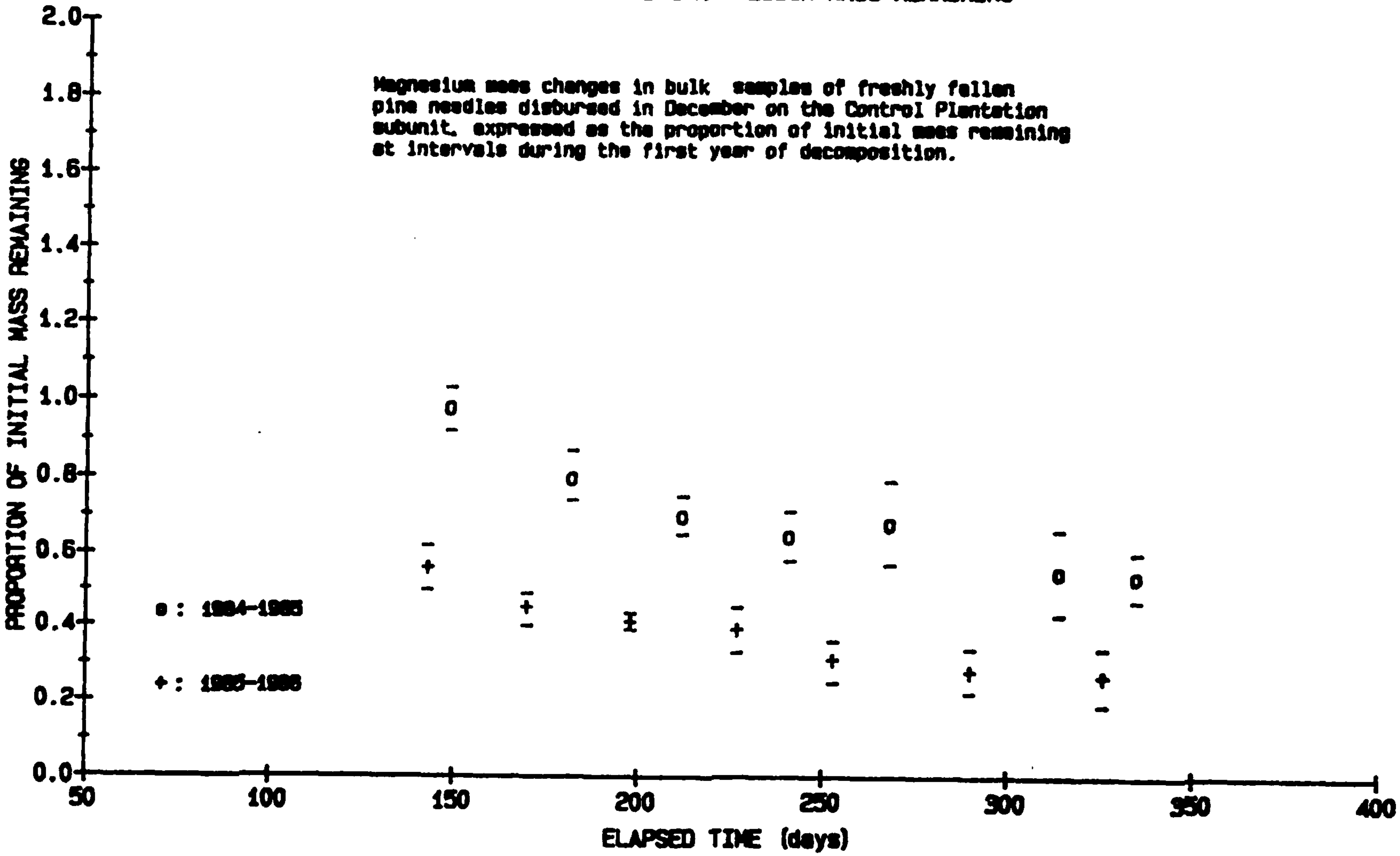


FIGURE 107.

BULK PINE LITTER, ANTENNA HARDWOOD STAND

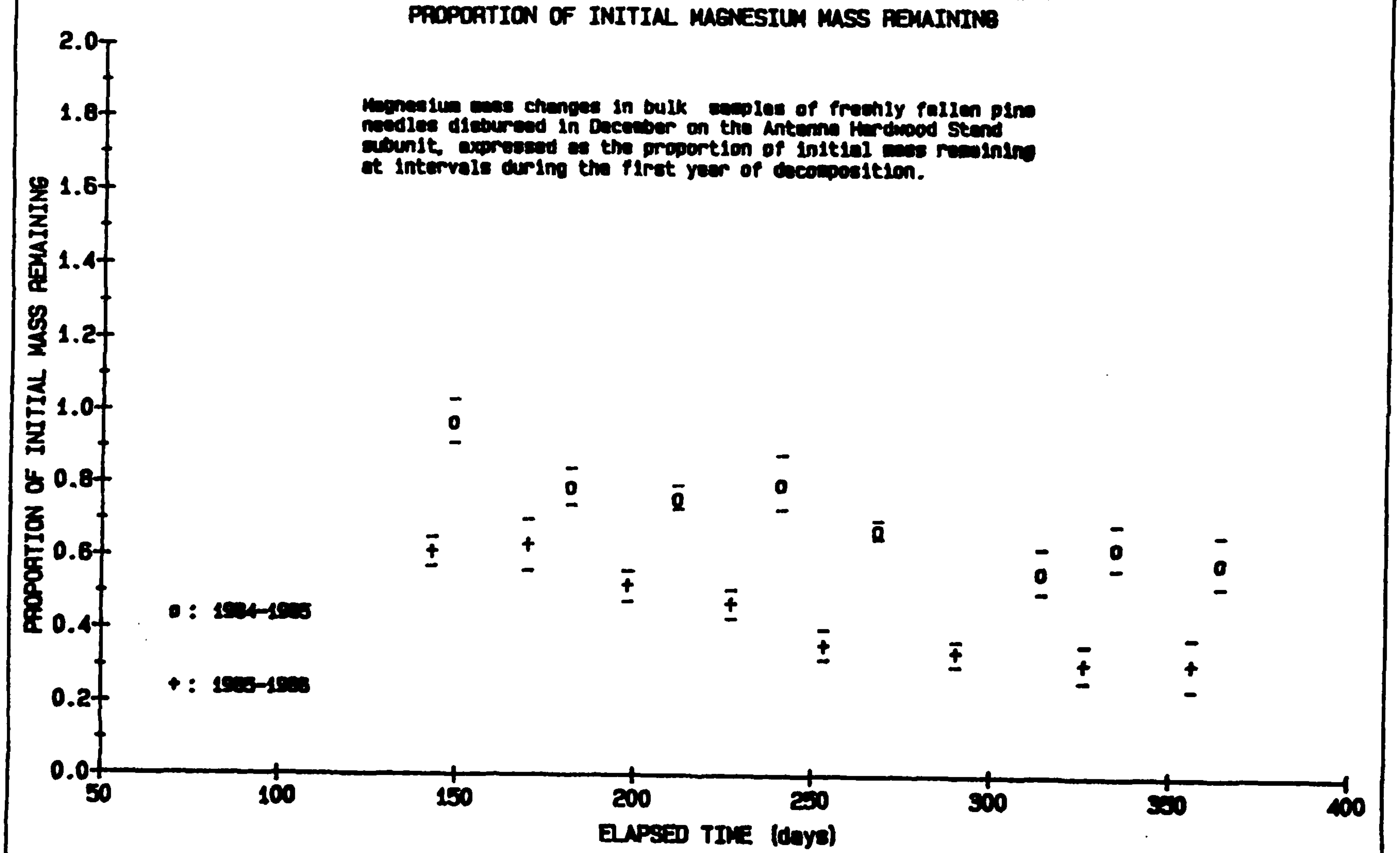
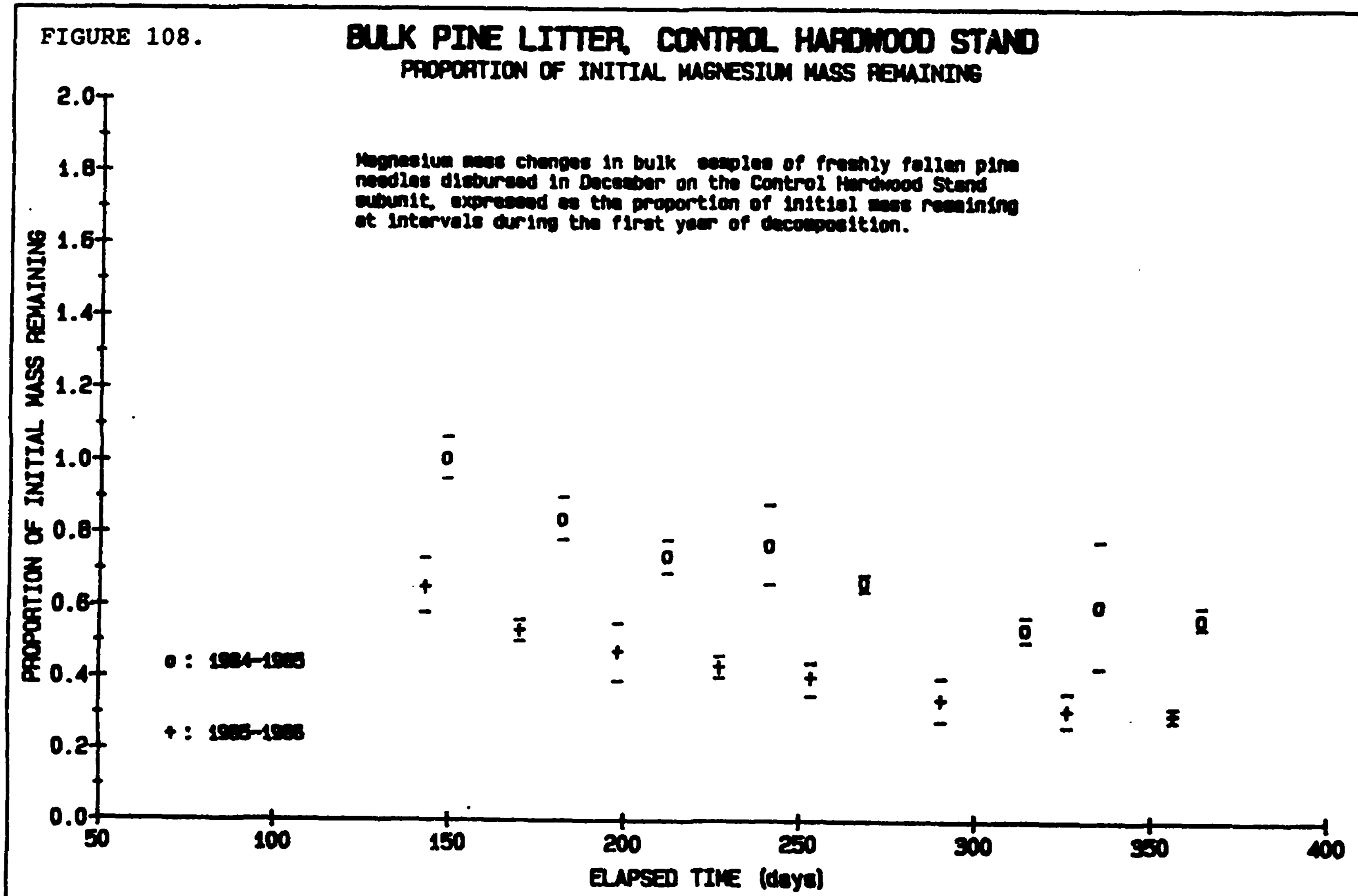
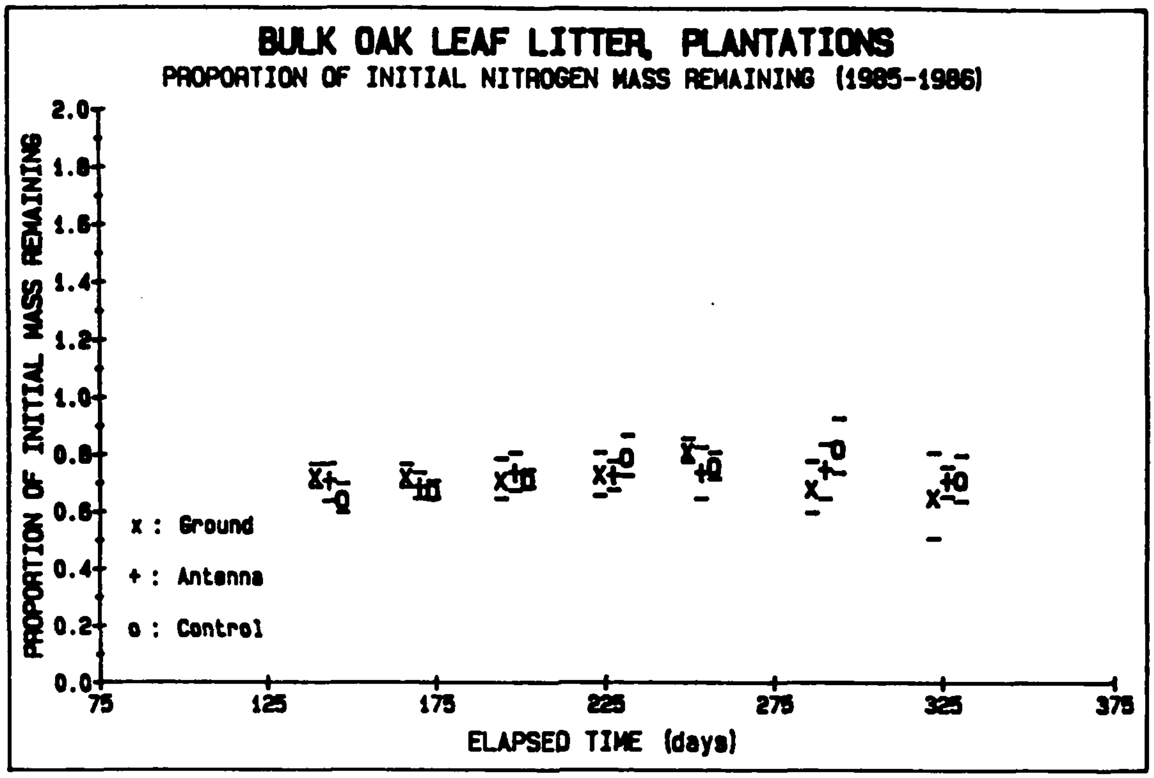


FIGURE 108.


BULK PINE LITTER, CONTROL HARDWOOD STAND
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING
Magnesium mass changes in bulk samples of freshly fallen pine needles disbursed in December on the Control Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
o : 1984-1985
+ : 1985-1986
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)


BULK OAK LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL NITROGEN MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

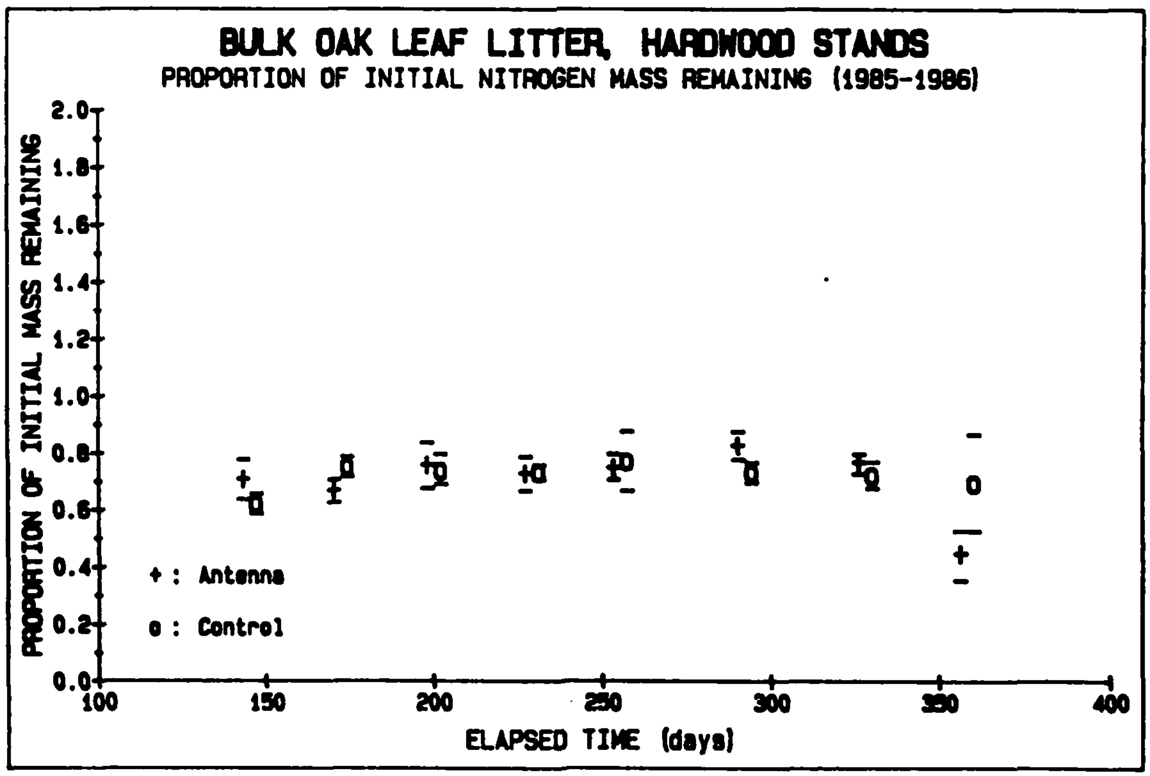
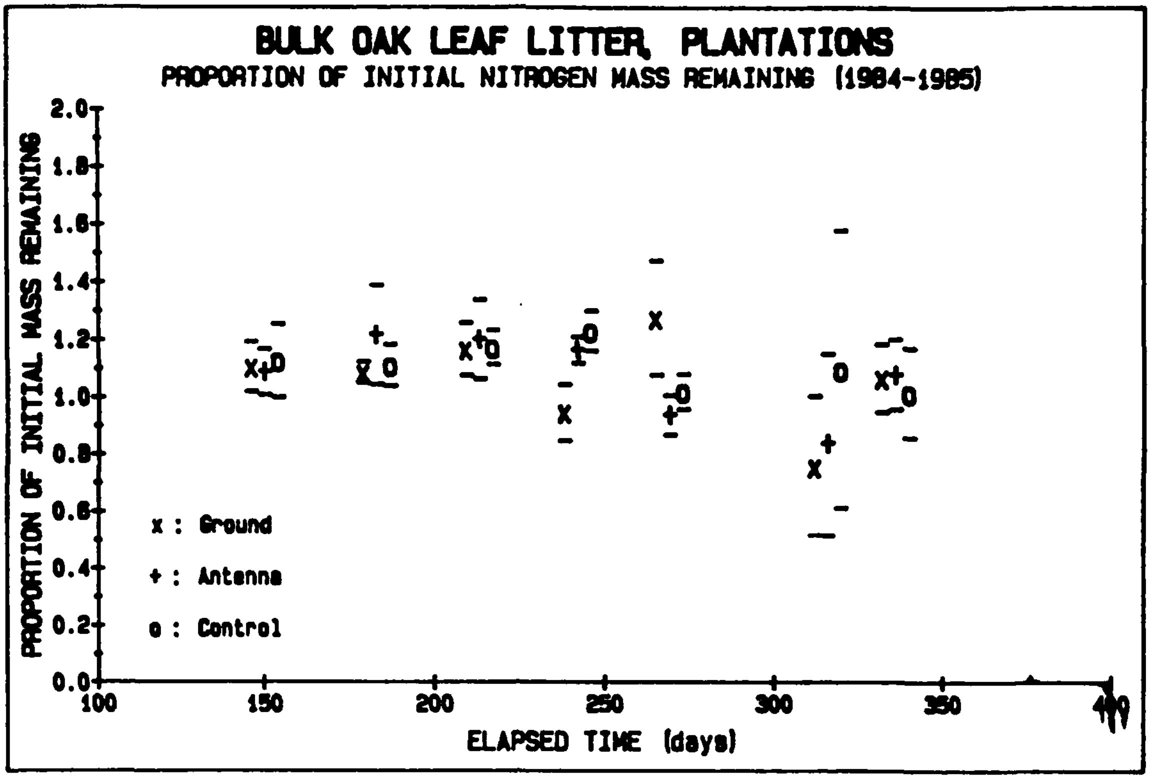
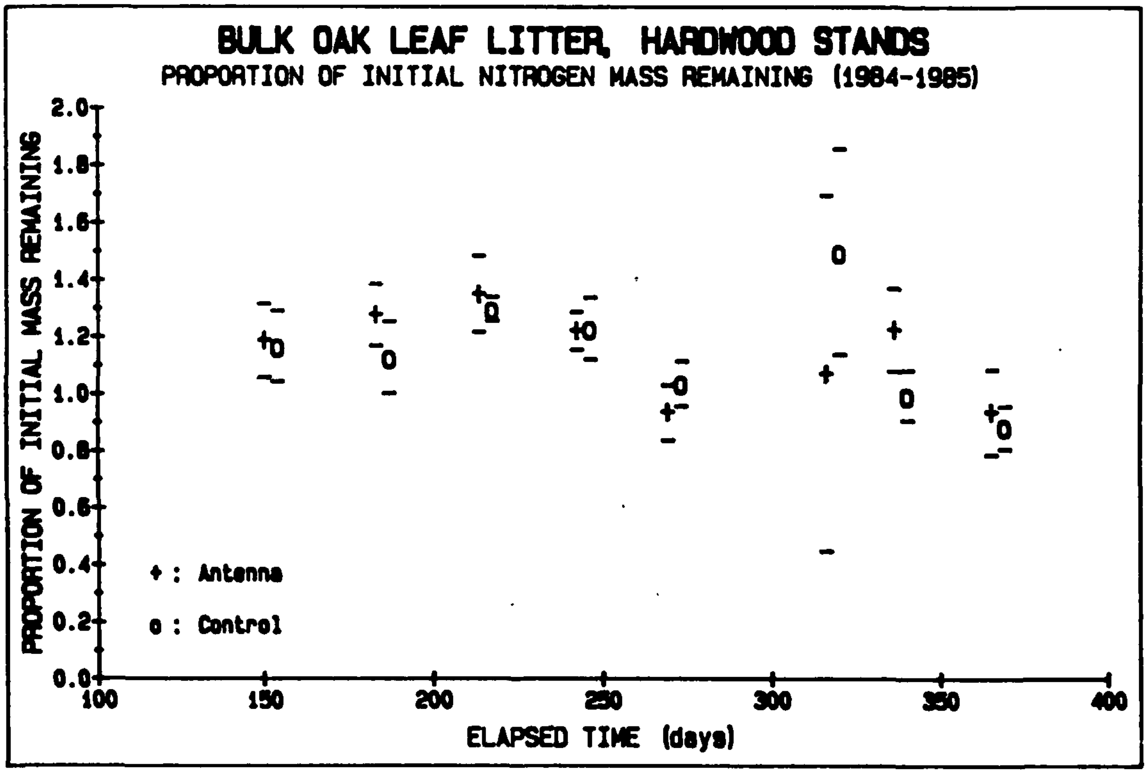

BULK OAK LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL NITROGEN MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 109.



BULK OAK LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL NITROGEN MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control



BULK OAK LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL NITROGEN MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
+ : Antenna
o : Control

FIGURE 110.

FIGURE 111.

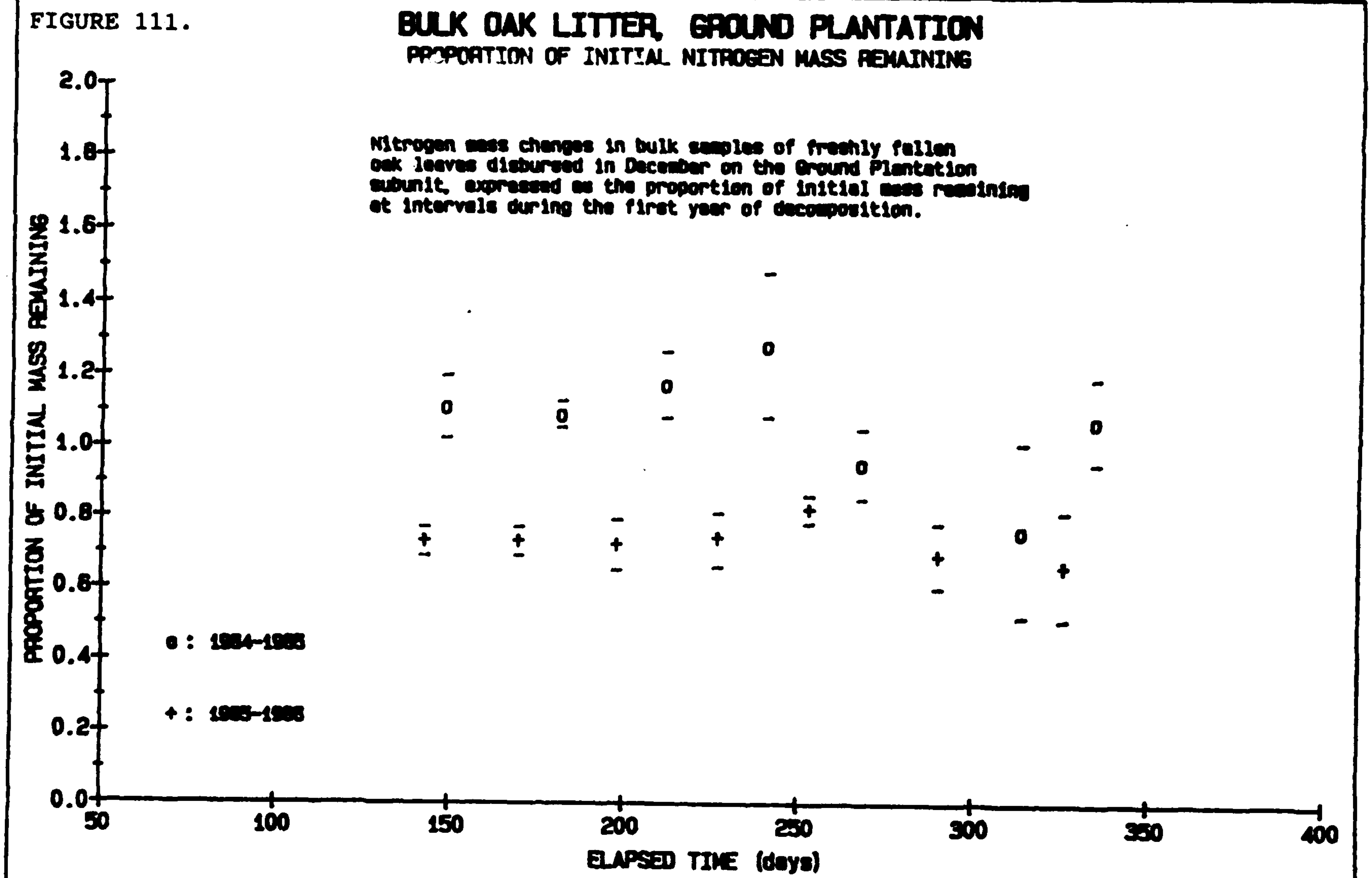

BULK OAK LITTER, GROUND PLANTATION
PROPORTION OF INITIAL NITROGEN MASS REMAINING
Nitrogen mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Ground Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
o : 1984-1985
+ : 1985-1986
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 112.

BULK OAK LITTER, ANTENNA PLANTATION

PROPORTION OF INITIAL NITROGEN MASS REMAINING

Nitrogen mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Antenna Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

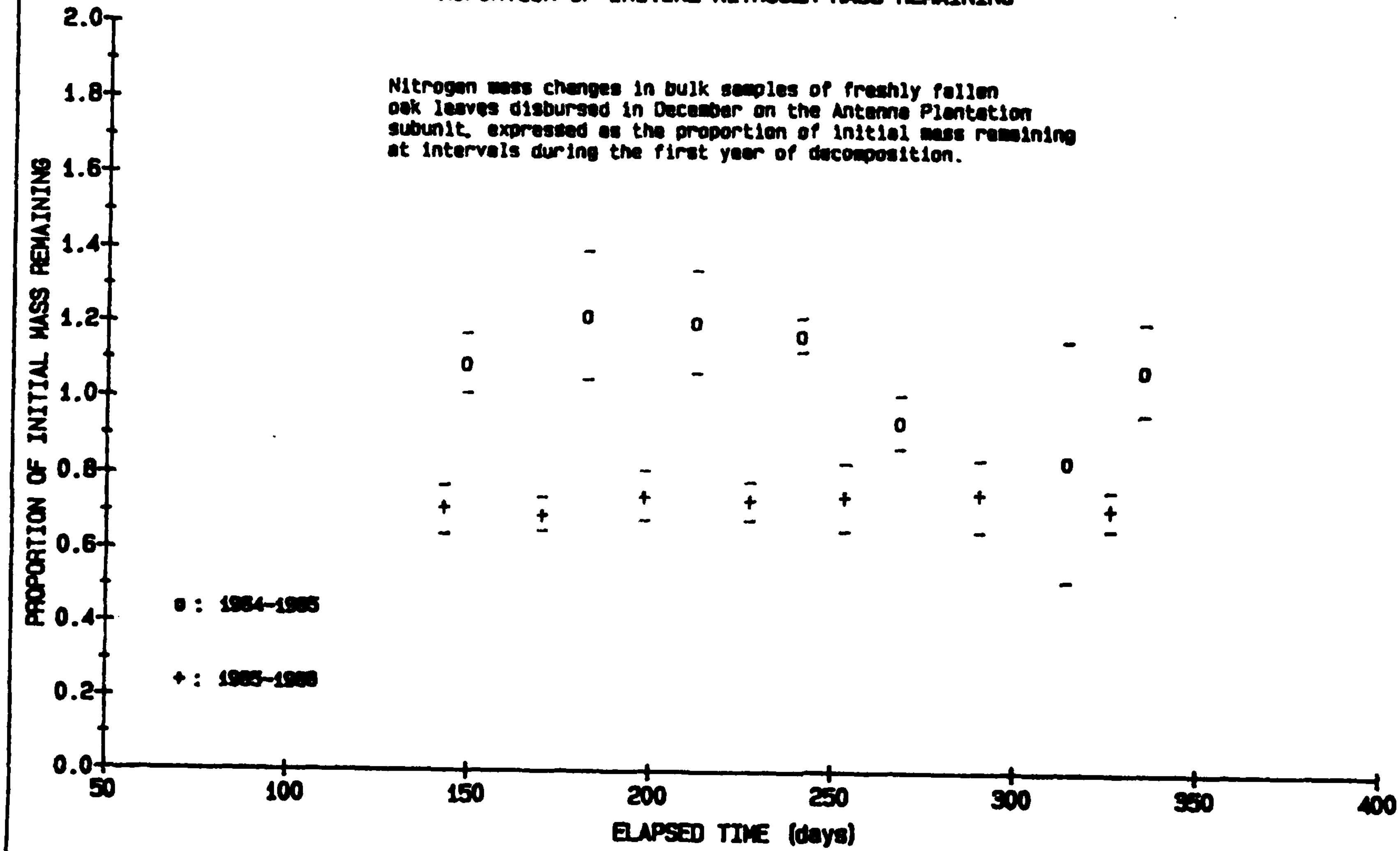


FIGURE 113.

BULK OAK LITTER, CONTROL PLANTATION
PROPORTION OF INITIAL NITROGEN MASS REMAINING

Nitrogen mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Control Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

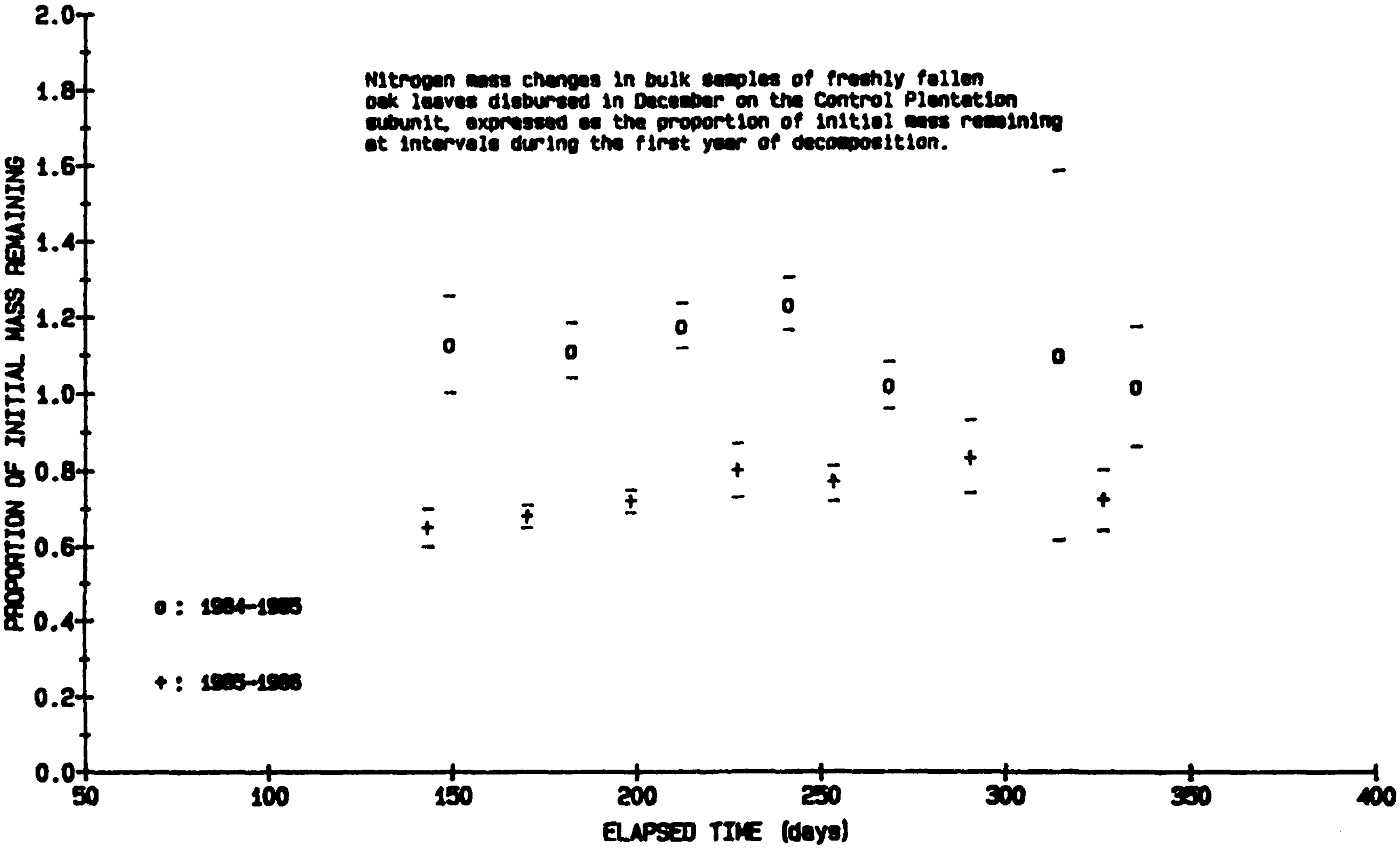


FIGURE 114.

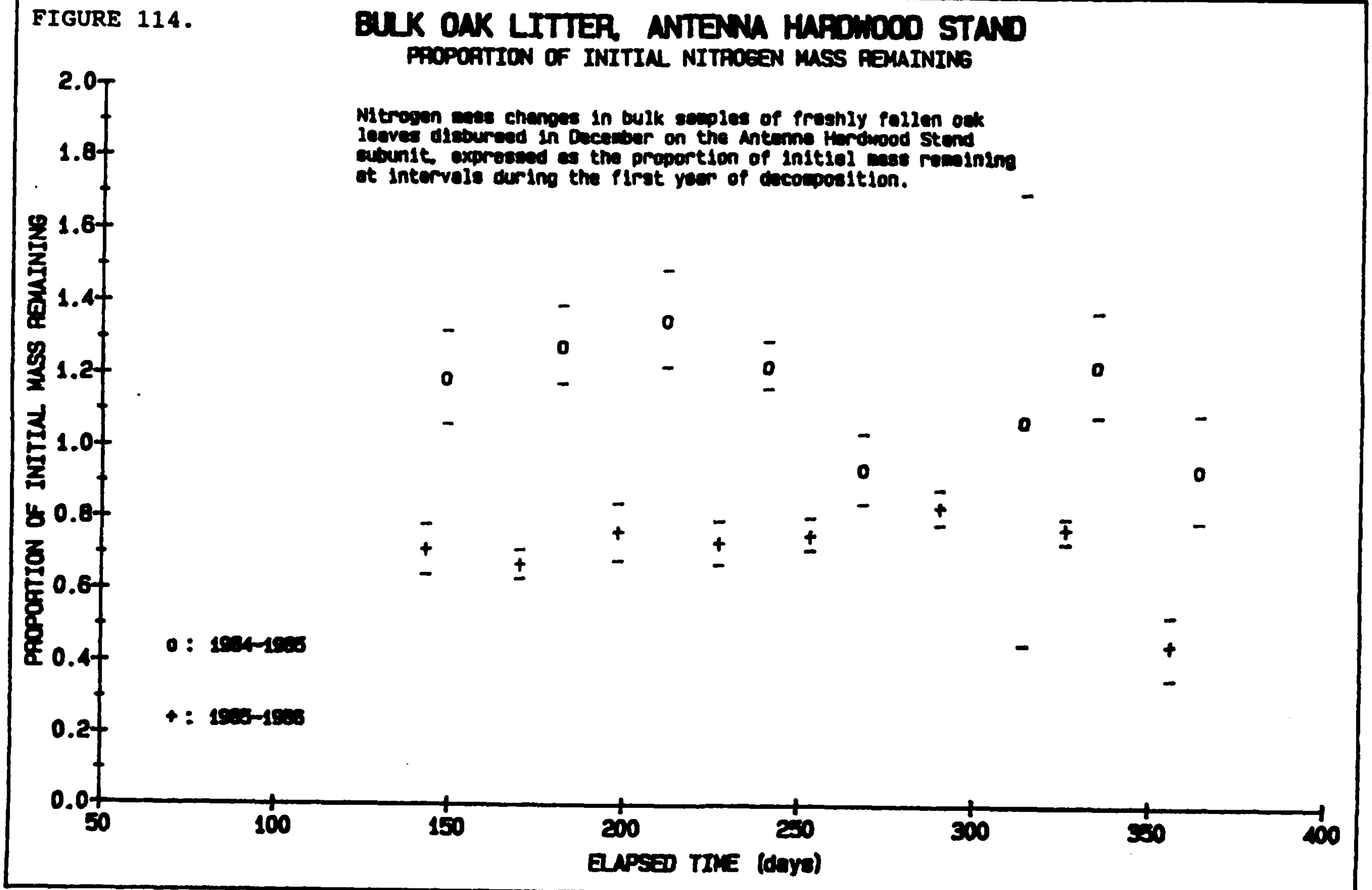
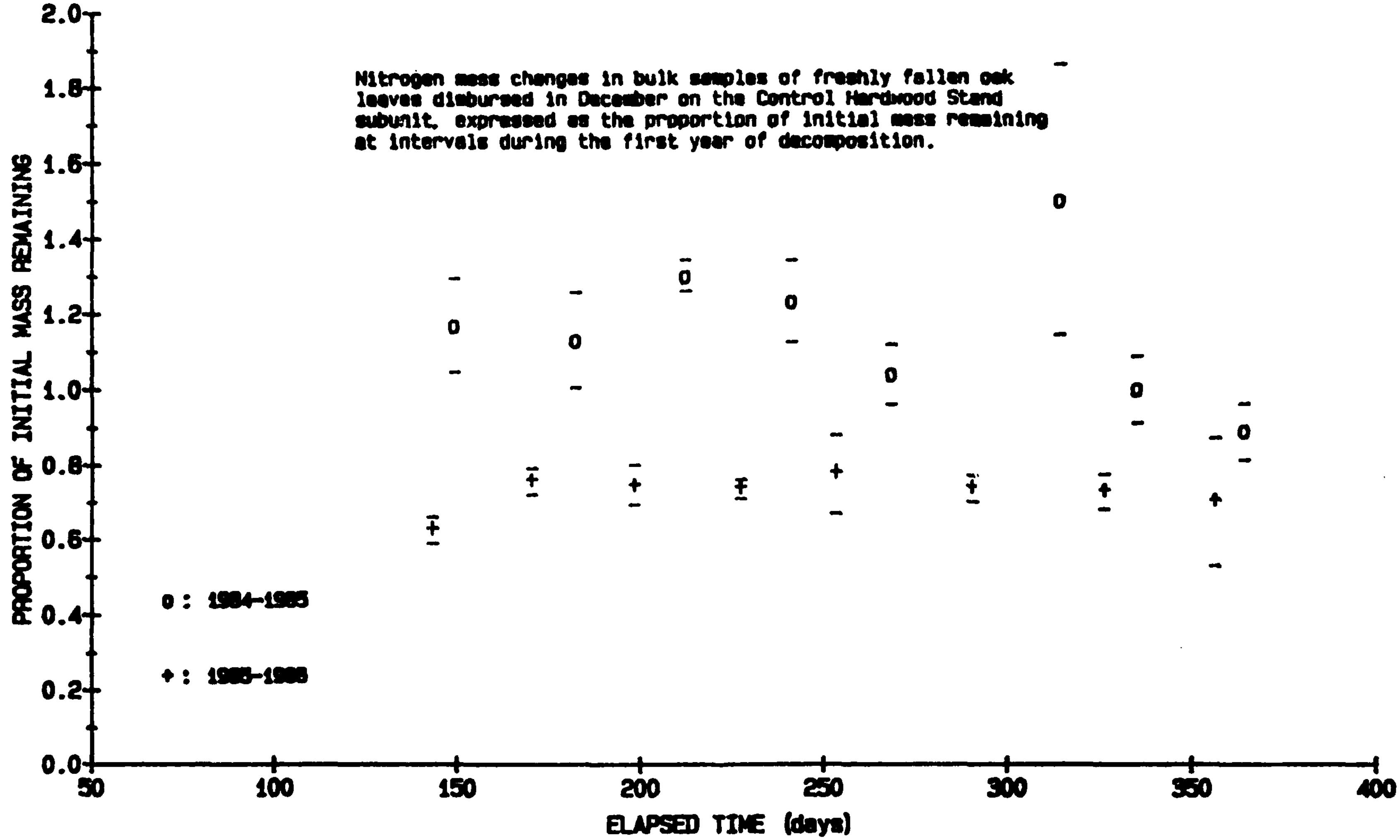
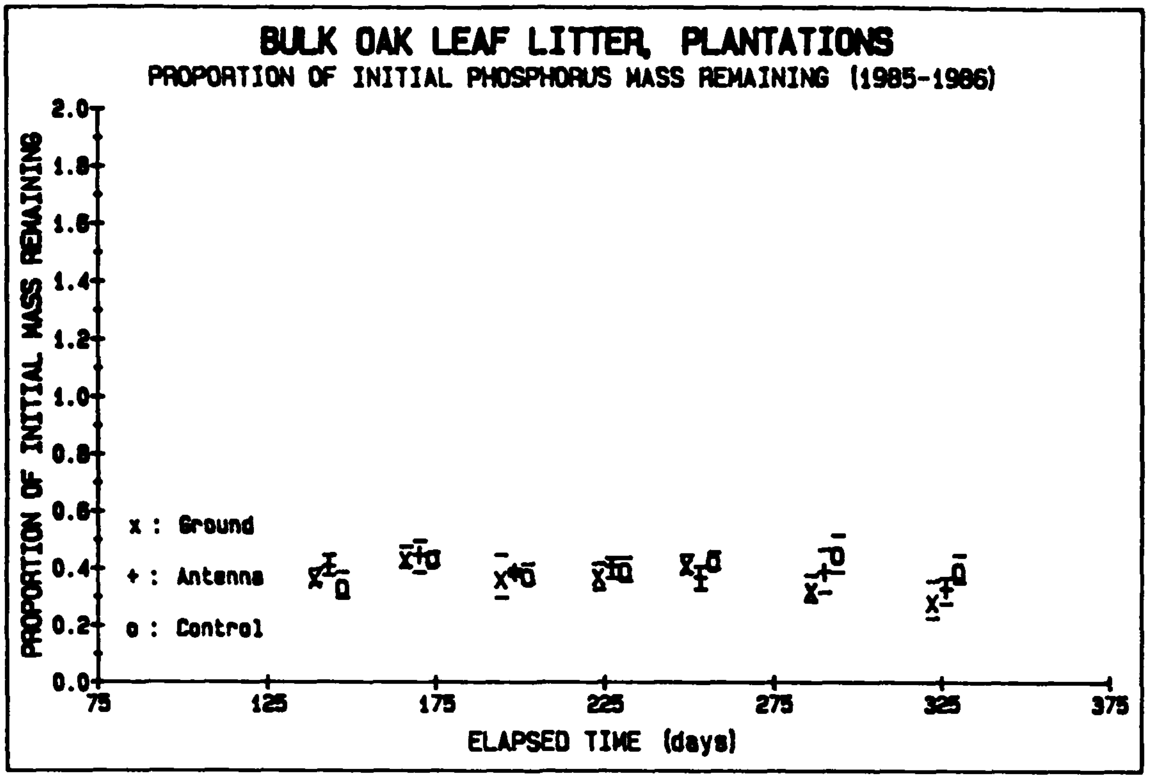

BULK OAK LITTER, ANTENNA HARDWOOD STAND
PROPORTION OF INITIAL NITROGEN MASS REMAINING
Nitrogen mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Antenna Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
o : 1984-1985
+ : 1985-1986
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 115.

BULK OAK LITTER, CONTROL HARDWOOD STAND

PROPORTION OF INITIAL NITROGEN MASS REMAINING




BULK OAK LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

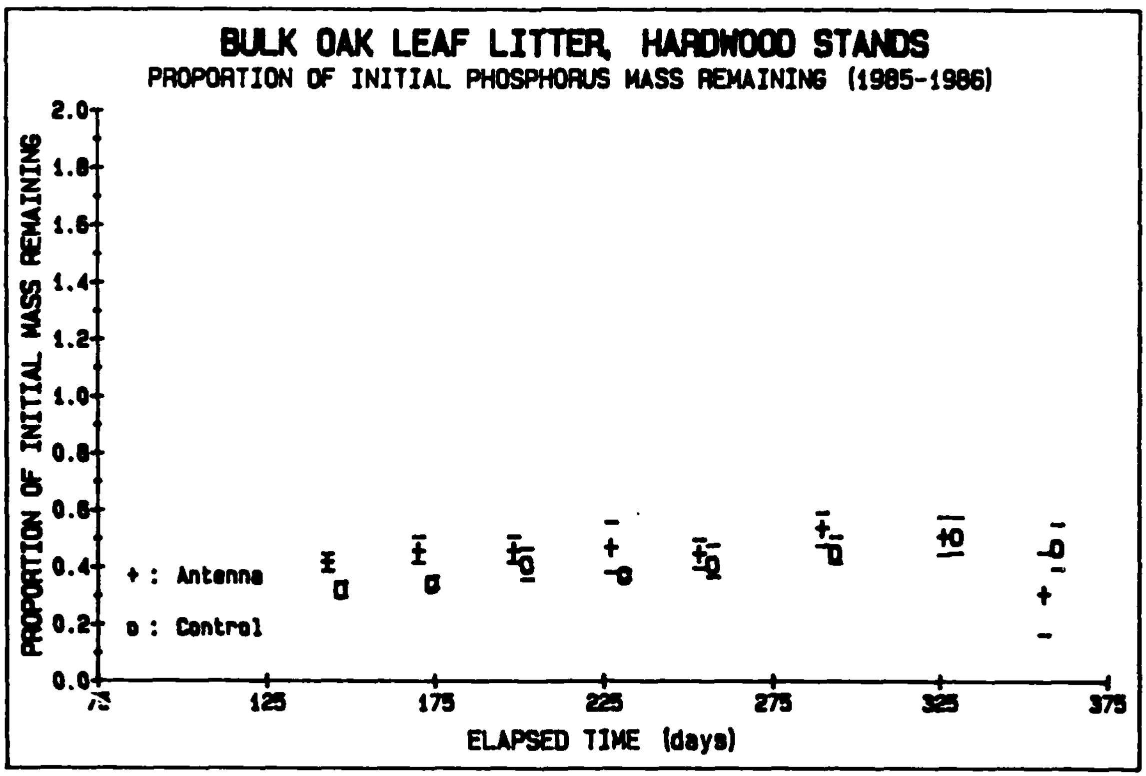
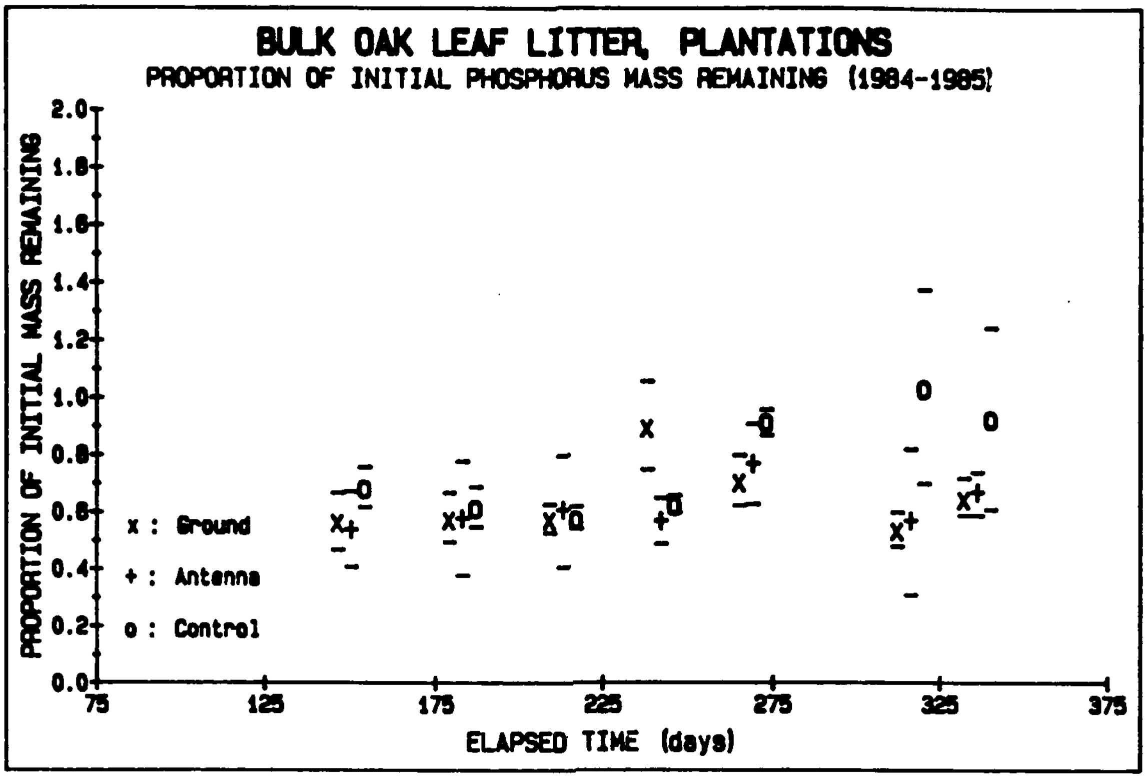

BULK OAK LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

FIGURE 116.


BULK OAK LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

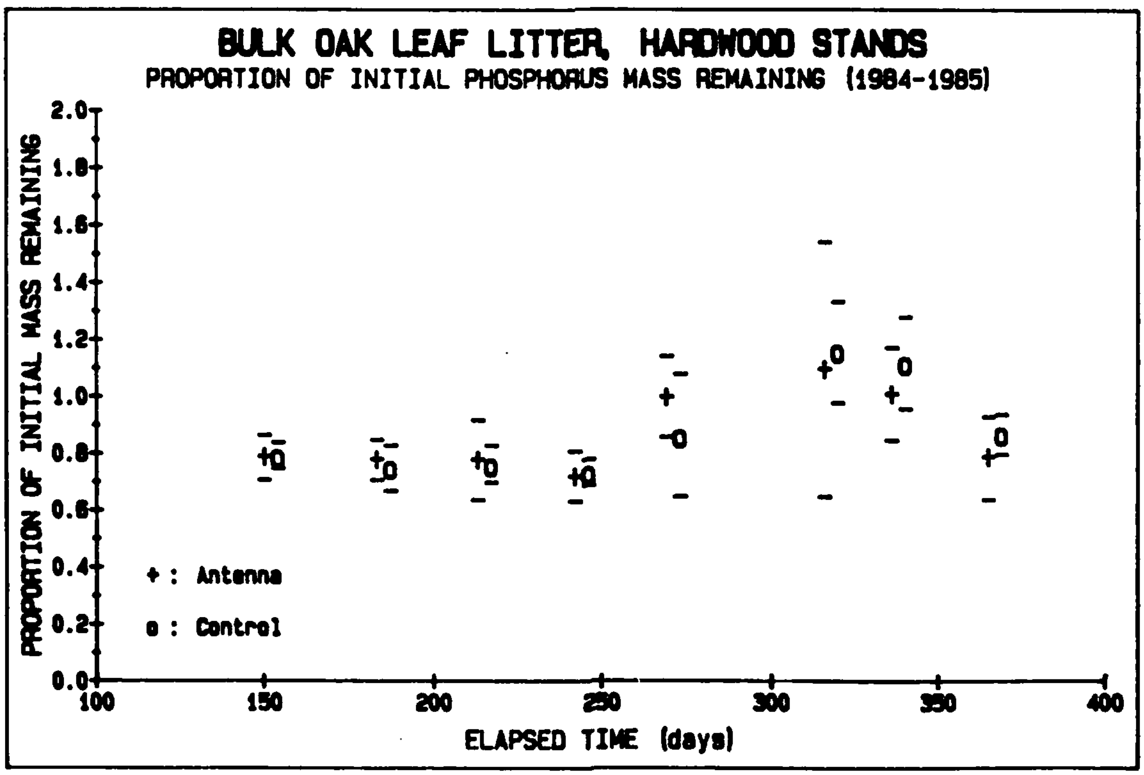

BULK OAK LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 117.

FIGURE 118.

BULK OAK LITTER, GROUND PLANTATION
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING

Phosphorus mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Ground Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

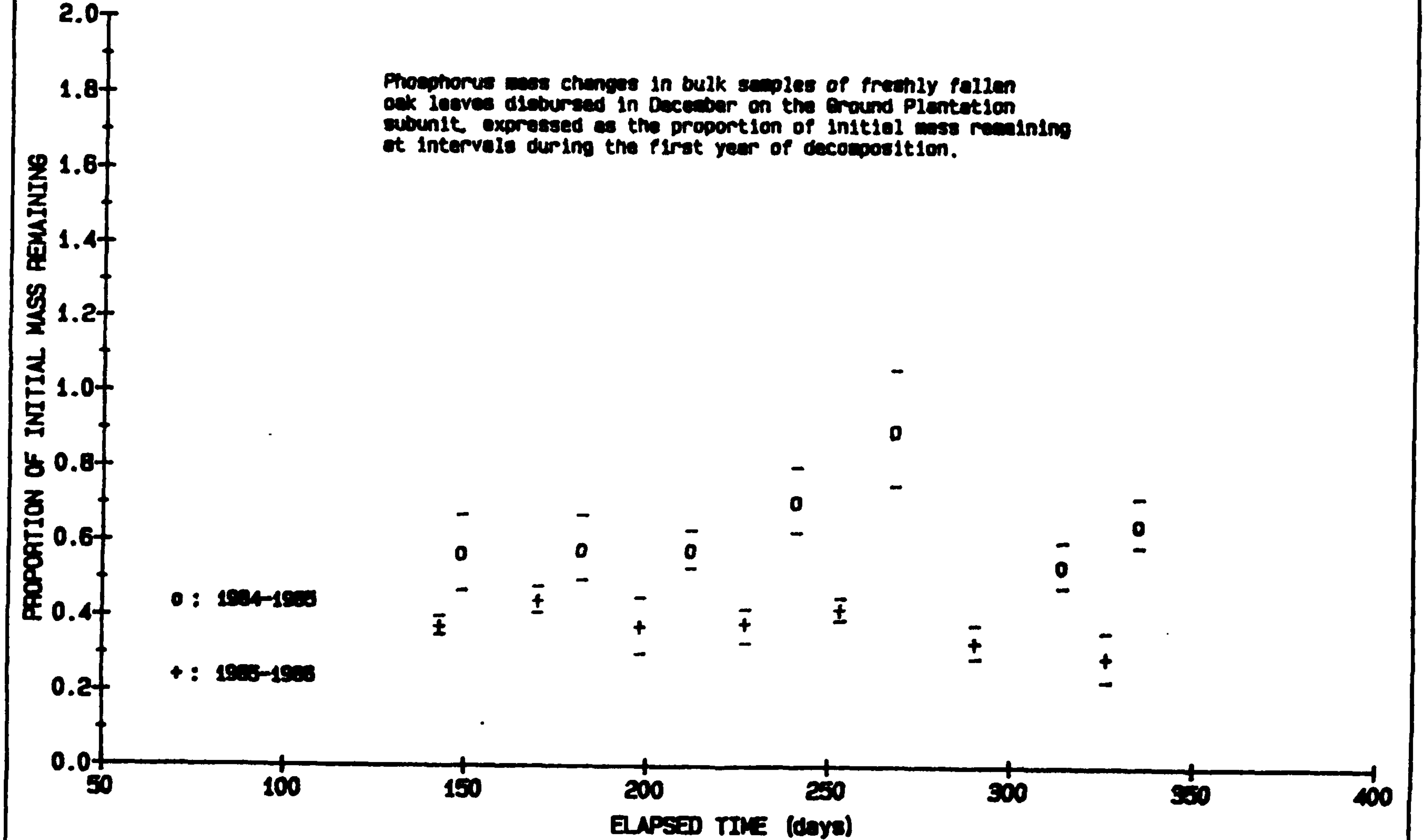


FIGURE 119.

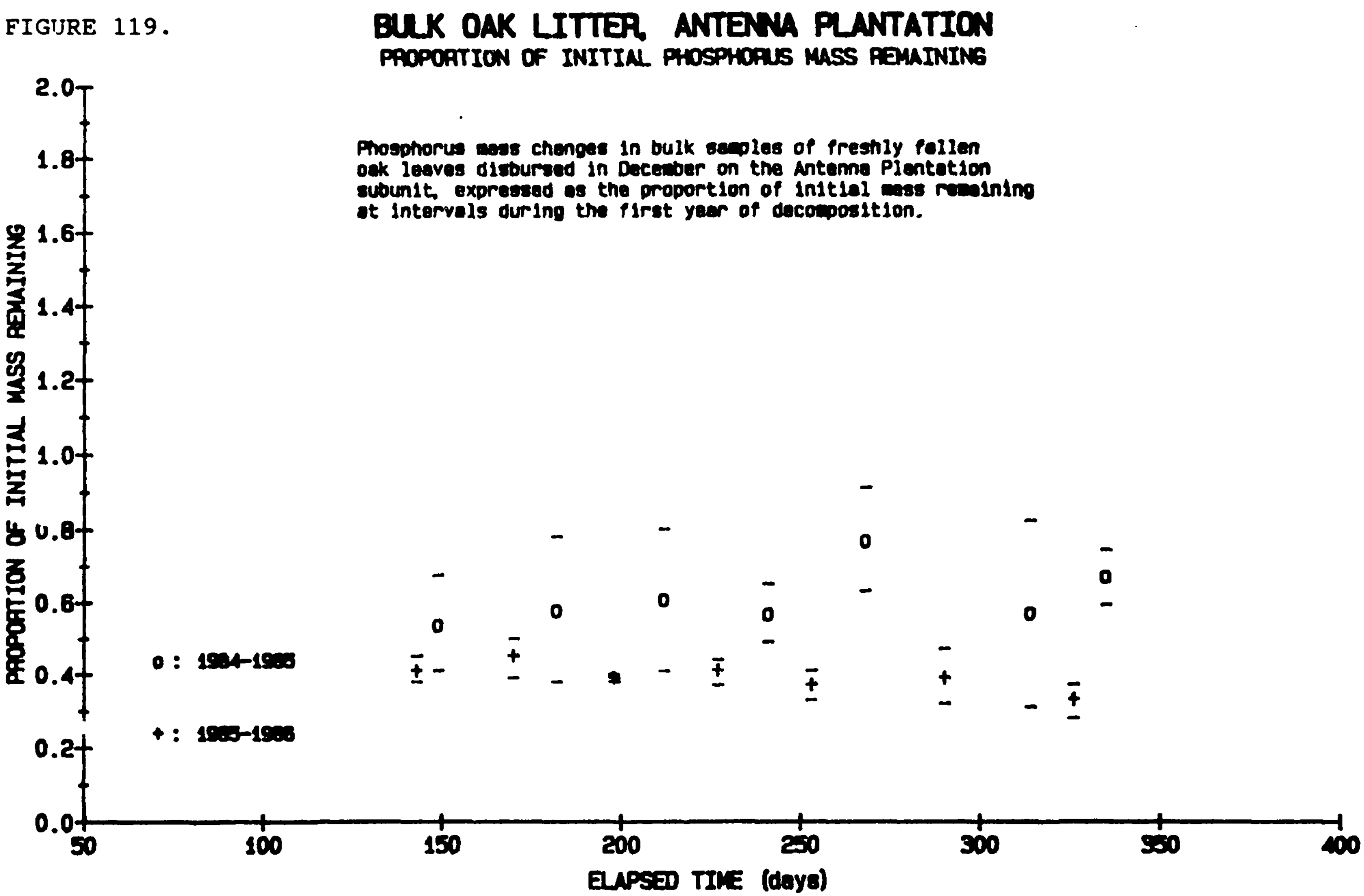
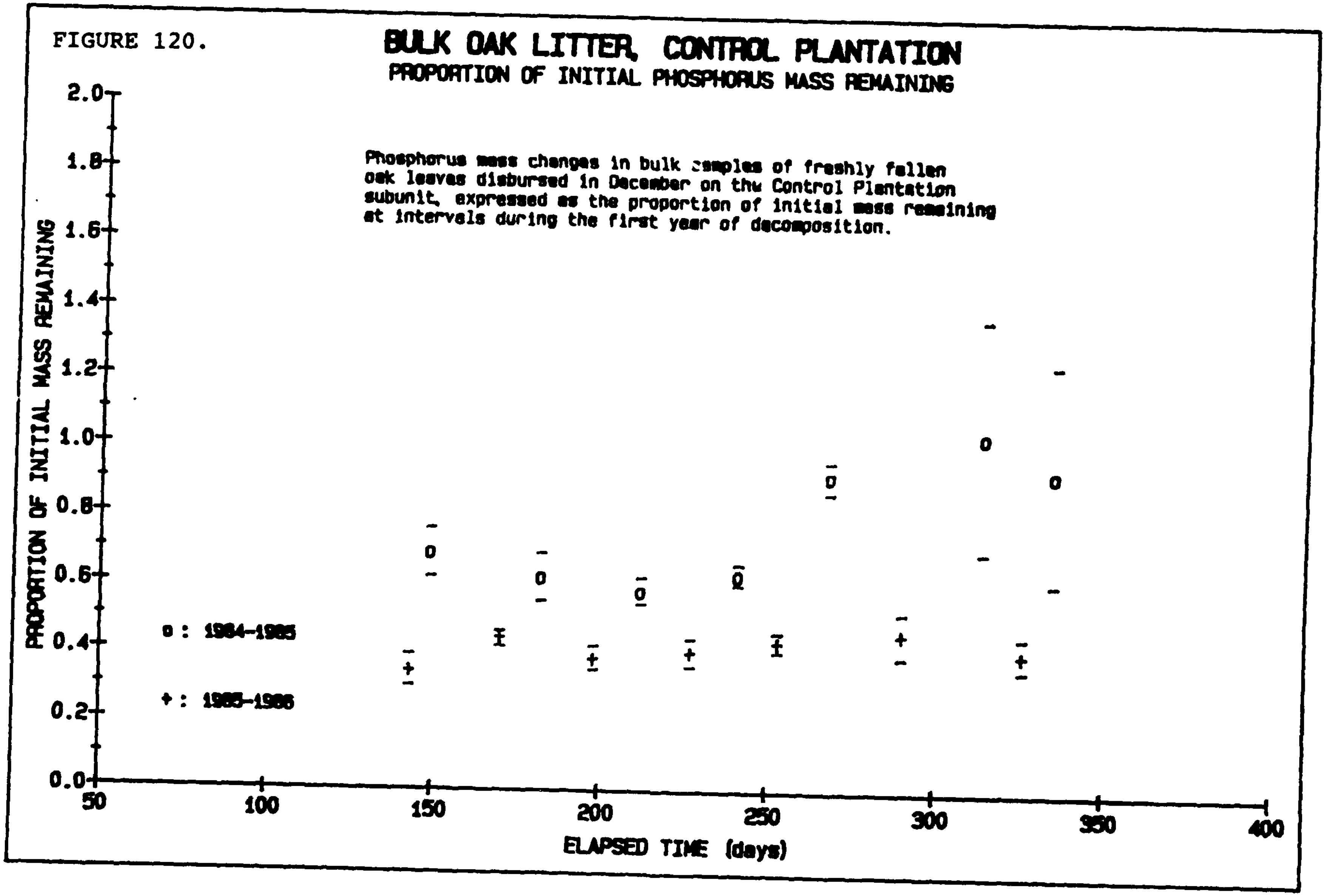

BULK OAK LITTER, ANTENNA PLANTATION
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING
Phosphorus mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Antenna Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
o : 1984-1985
+ : 1985-1986
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 120.



BULK OAK LITTER, CONTROL PLANTATION
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING
Phosphorus mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Control Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
o : 1984-1985
+ : 1985-1986
PROPORTION OF INITIAL MASS REMAINING
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 121.

BULK OAK LITTER, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING

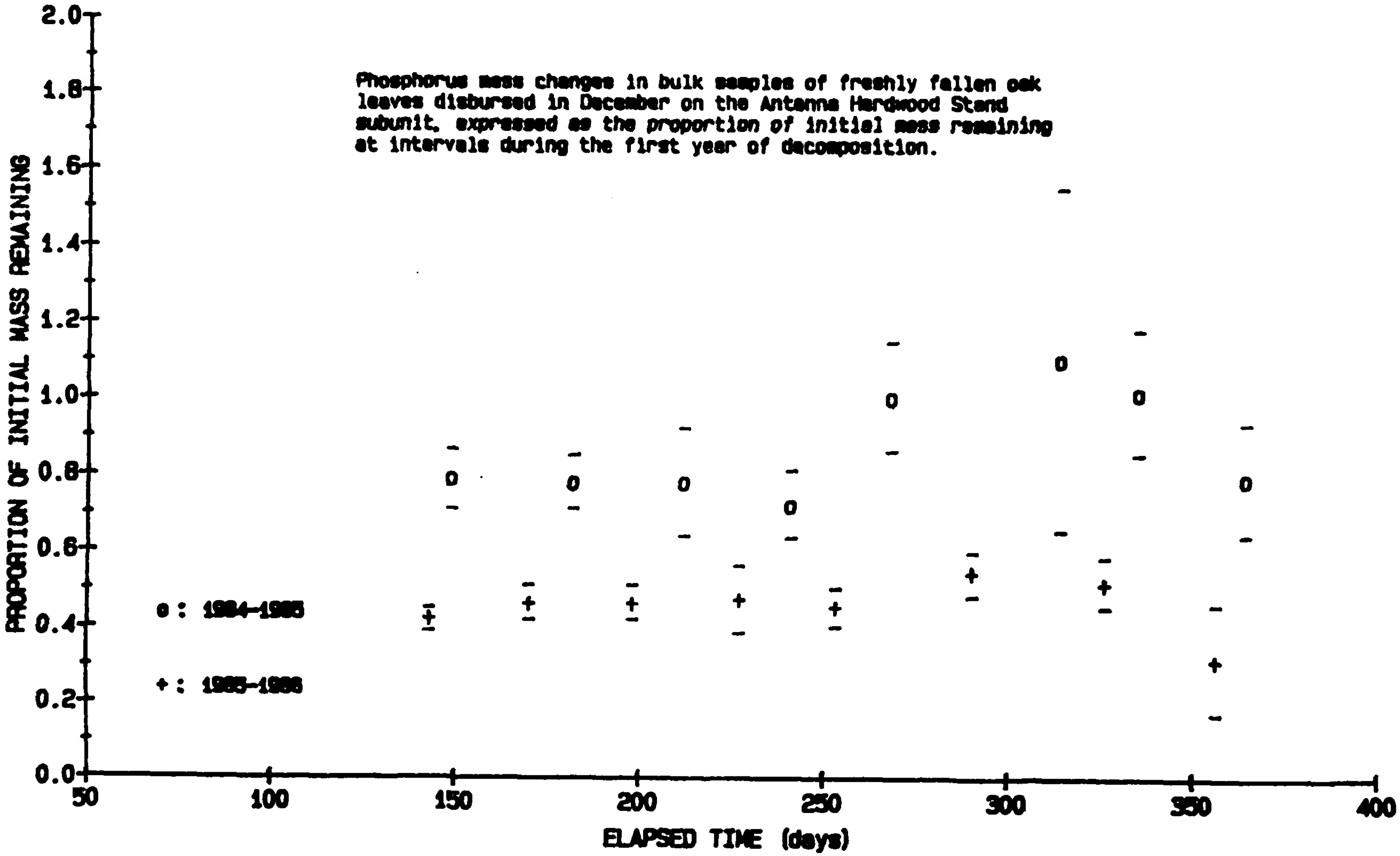
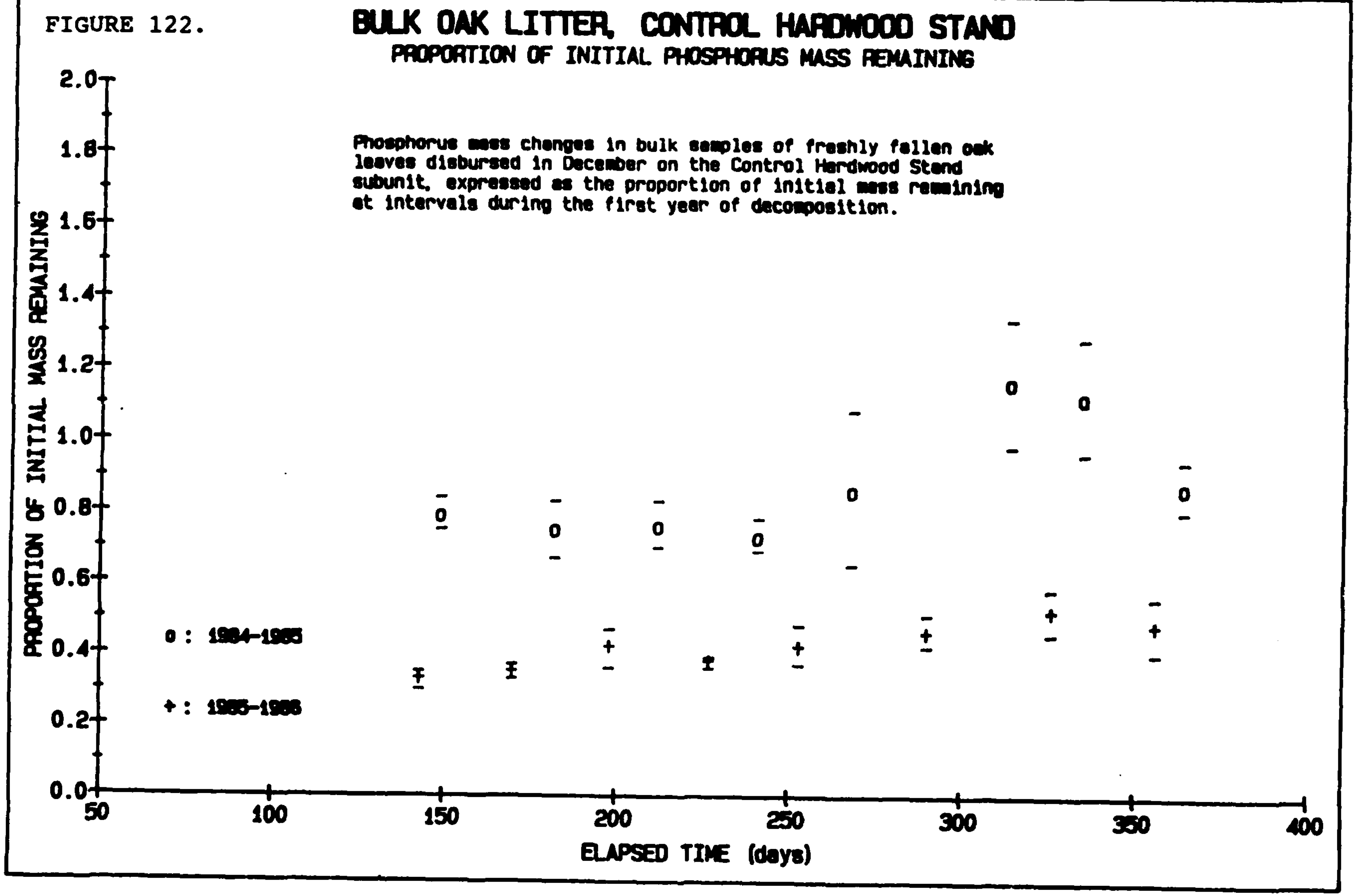
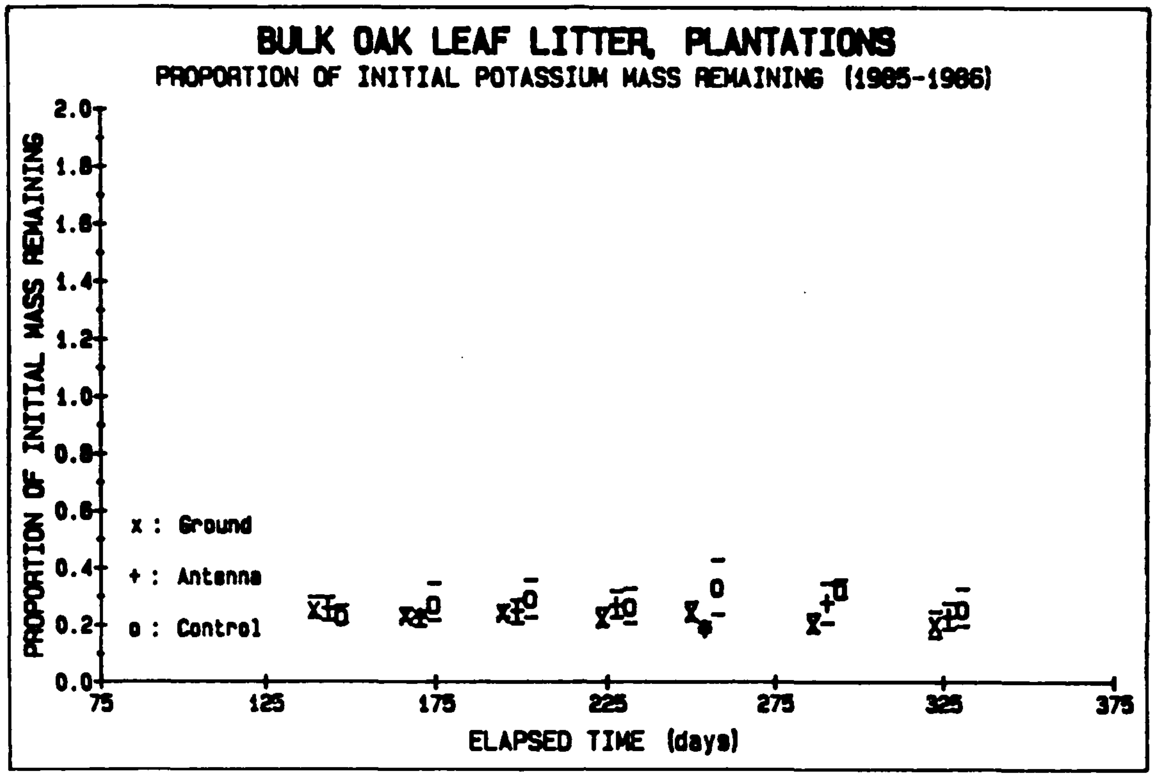


FIGURE 122.


BULK OAK LITTER, CONTROL HARDWOOD STAND
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING
Phosphorus mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Control Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
o : 1984-1985
+ : 1985-1986
PROPORTION OF INITIAL MASS REMAINING
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
ELAPSED TIME (days)
50
100
150
200
250
300
350
400


BULK OAK LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

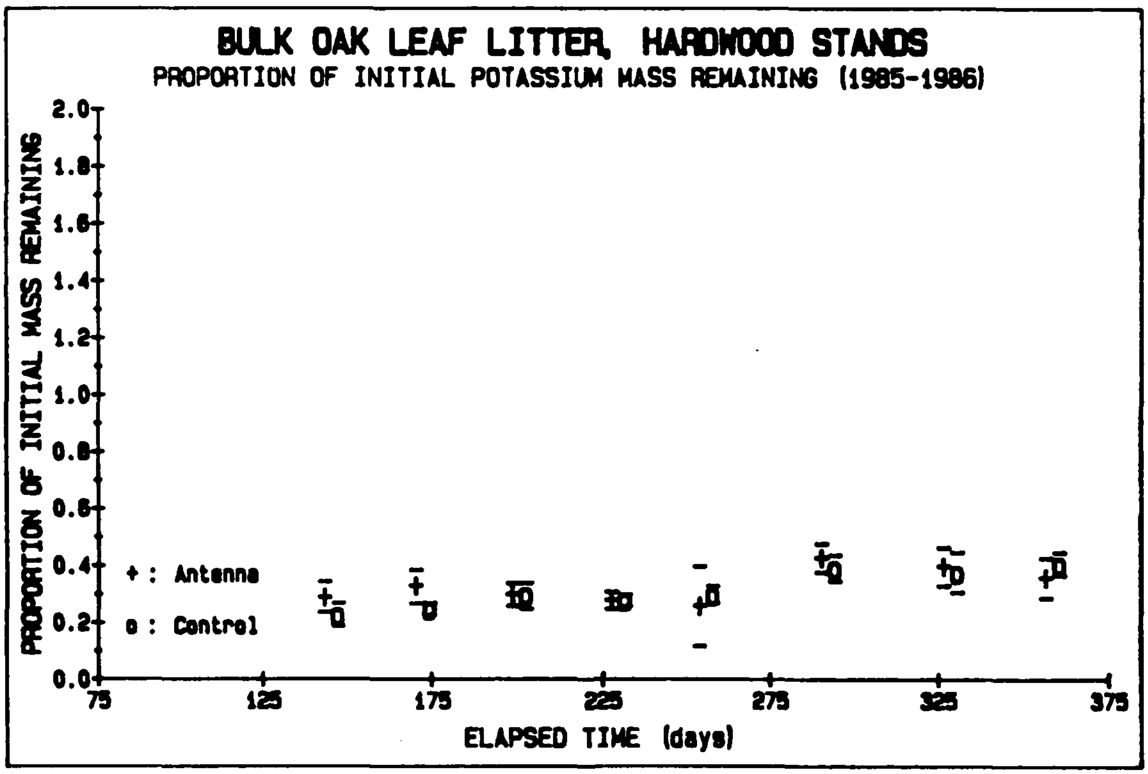
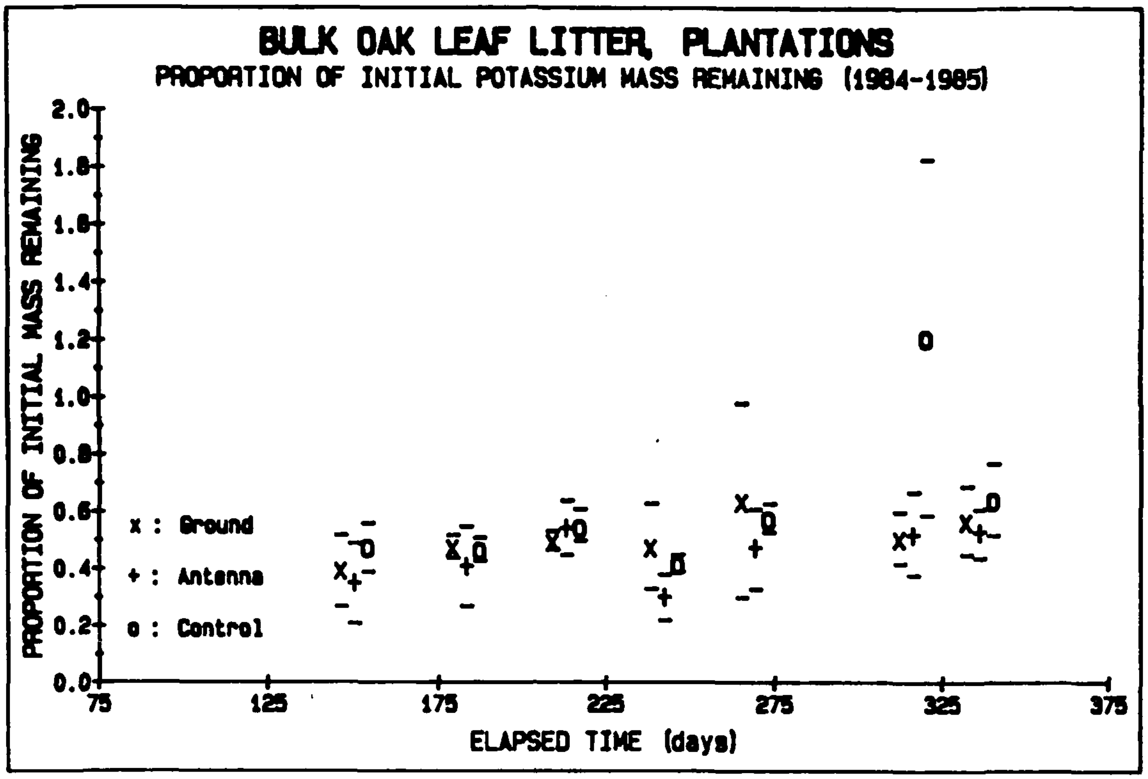

BULK OAK LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

FIGURE 123.


BULK OAK LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
75
125
175
225
275
325
375

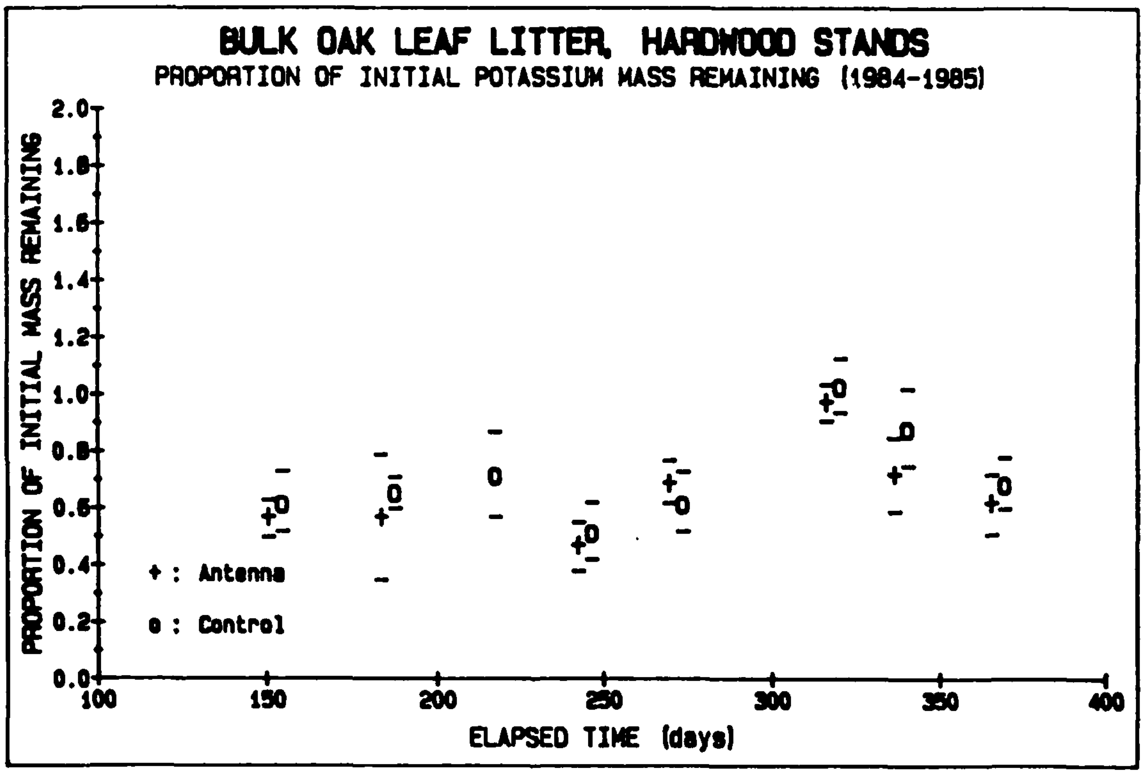

BULK OAK LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
+ : Antenna
o : Control
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
100
150
200
250
300
350
400

FIGURE 124.

FIGURE 125.

BULK OAK LITTER, GROUND PLANTATION

PROPORTION OF INITIAL POTASSIUM MASS REMAINING

Potassium mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Ground Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

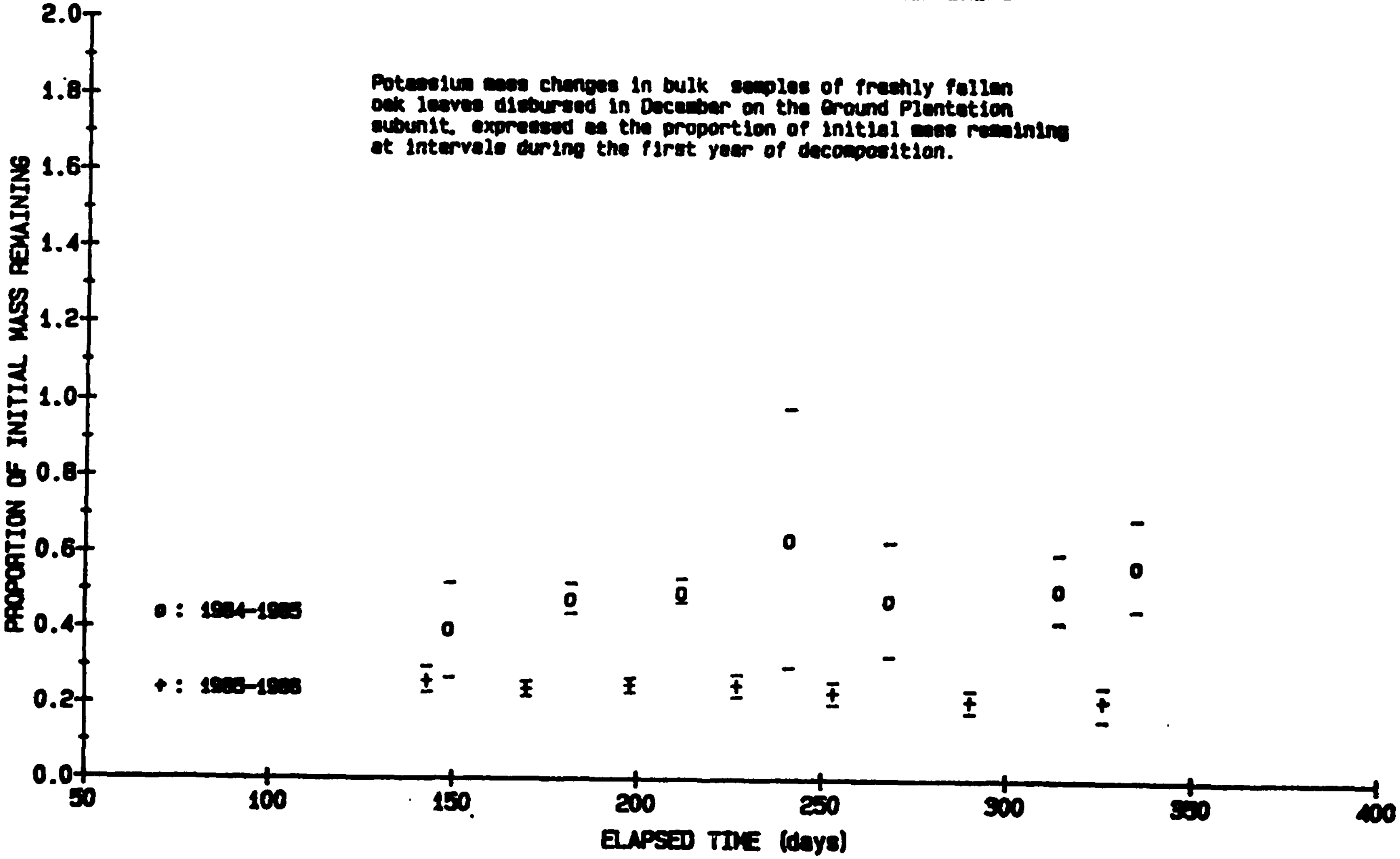


FIGURE 126.

BULK OAK LITTER, ANTENNA PLANTATION

PROPORTION OF INITIAL POTASSIUM MASS REMAINING

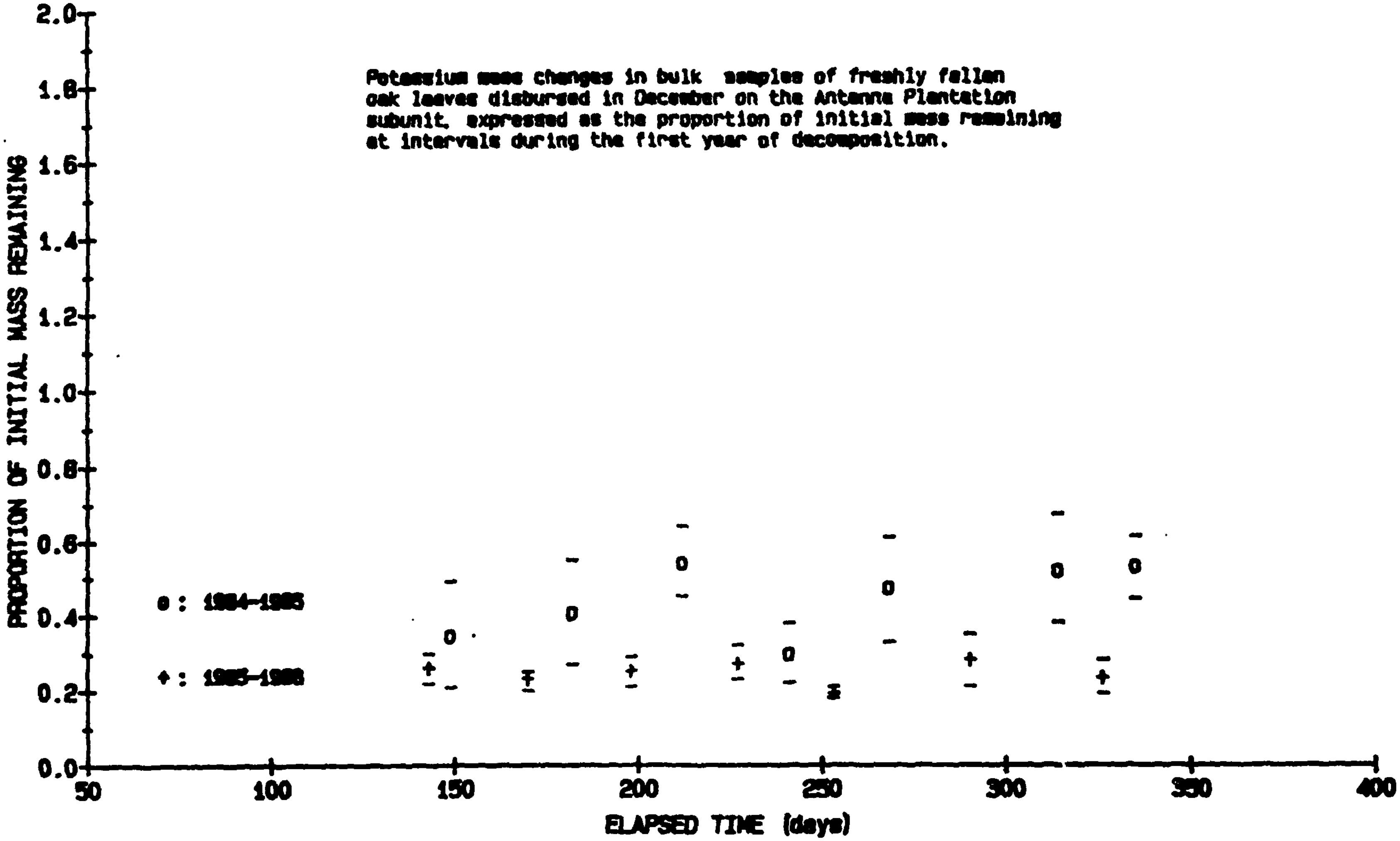


FIGURE 127.

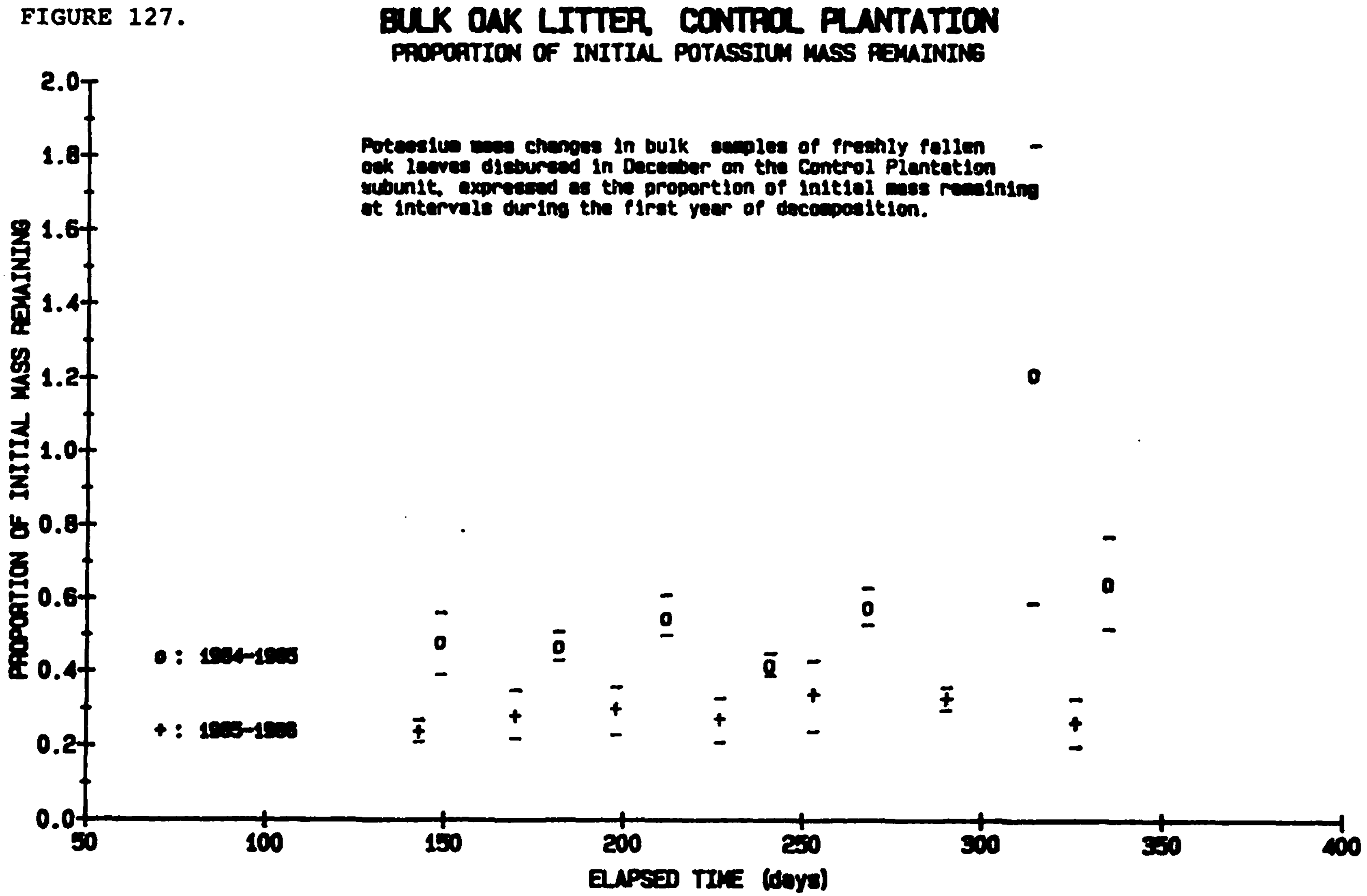

BULK OAK LITTER, CONTROL PLANTATION
PROPORTION OF INITIAL POTASSIUM MASS REMAINING
Potassium mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Control Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
o : 1984-1985
+ : 1985-1986
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 128.

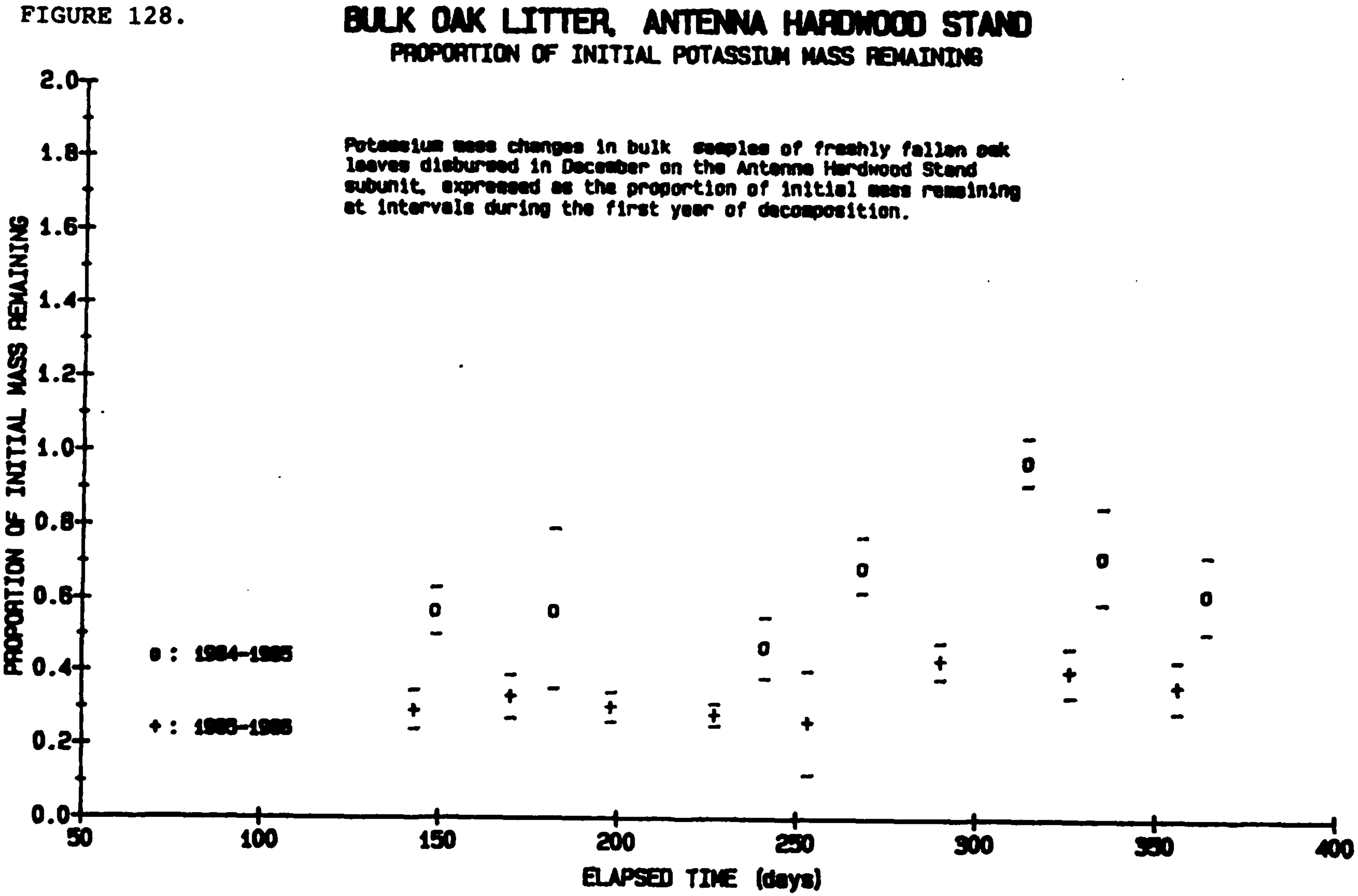
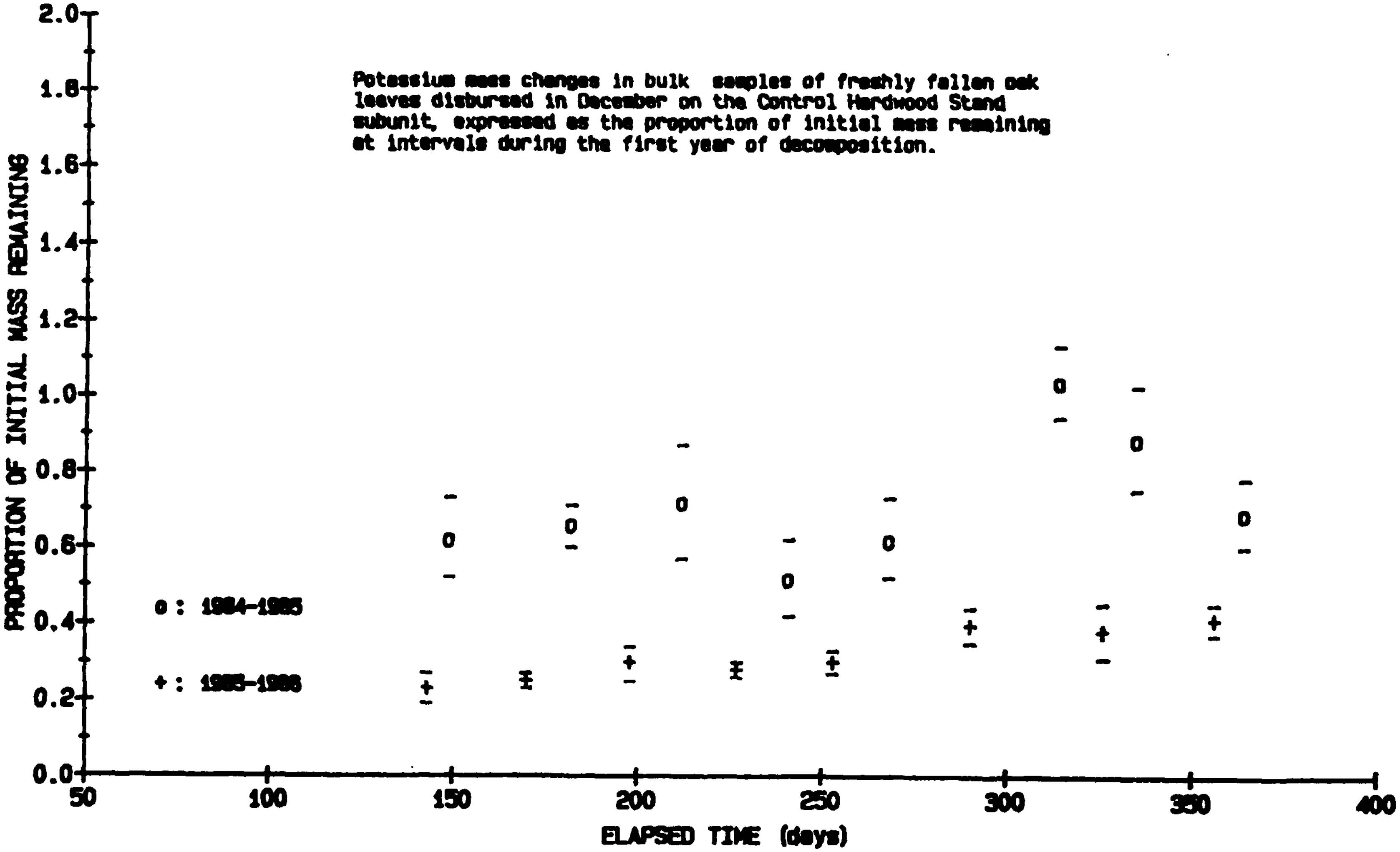

BULK OAK LITTER, ANTENNA HARDWOOD STAND
PROPORTION OF INITIAL POTASSIUM MASS REMAINING
Potassium mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Antenna Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
o : 1984-1985
+ : 1985-1986
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

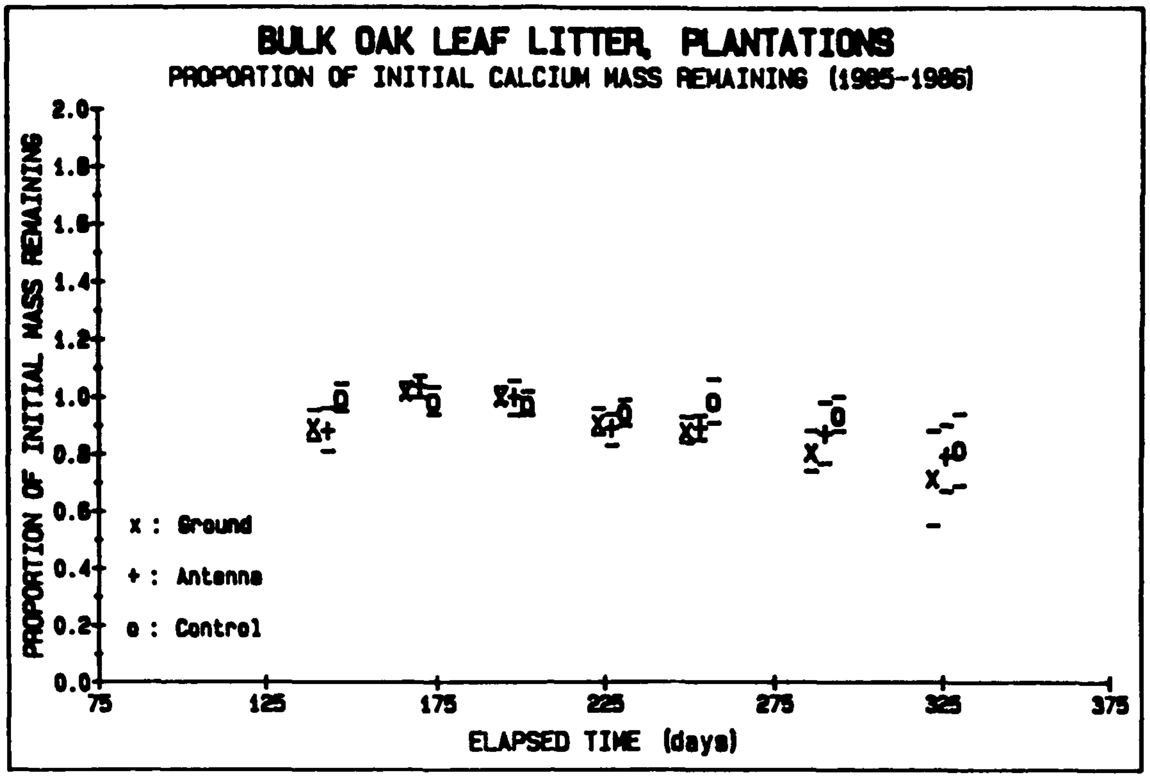
FIGURE 129.

BULK OAK LITTER, CONTROL HARDWOOD STAND

PROPORTION OF INITIAL POTASSIUM MASS REMAINING



Potassium mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Control Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.


BULK OAK LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL CALCIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

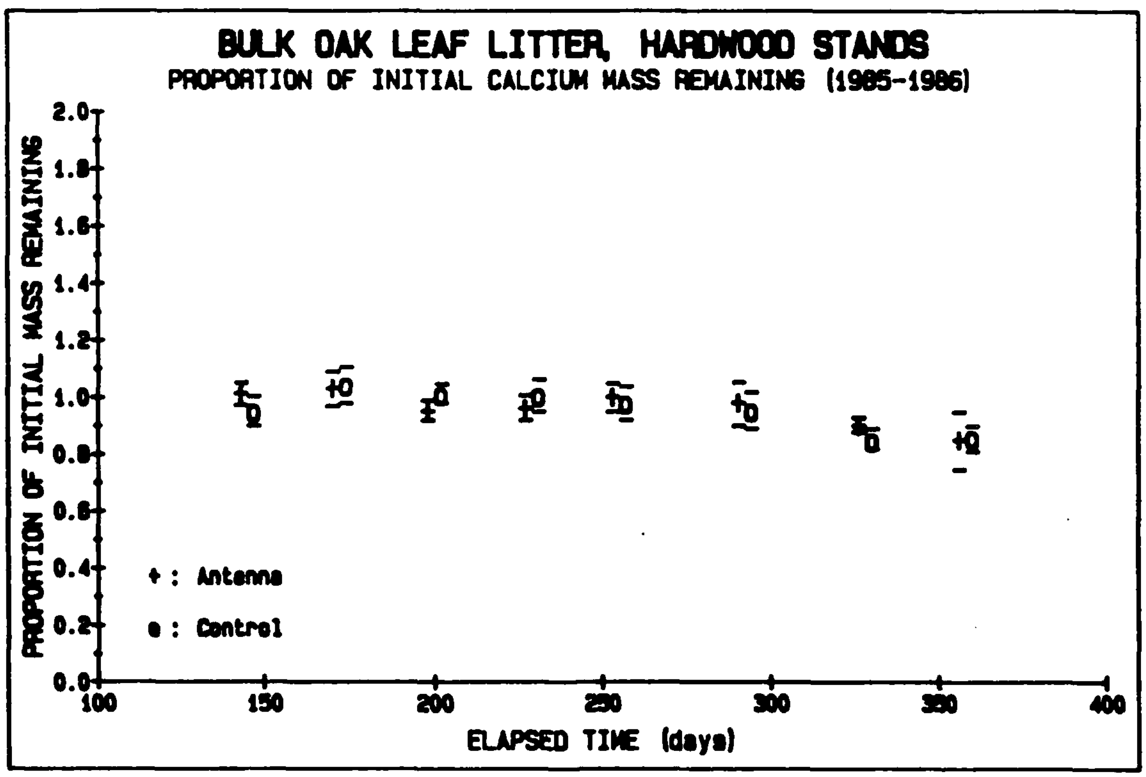
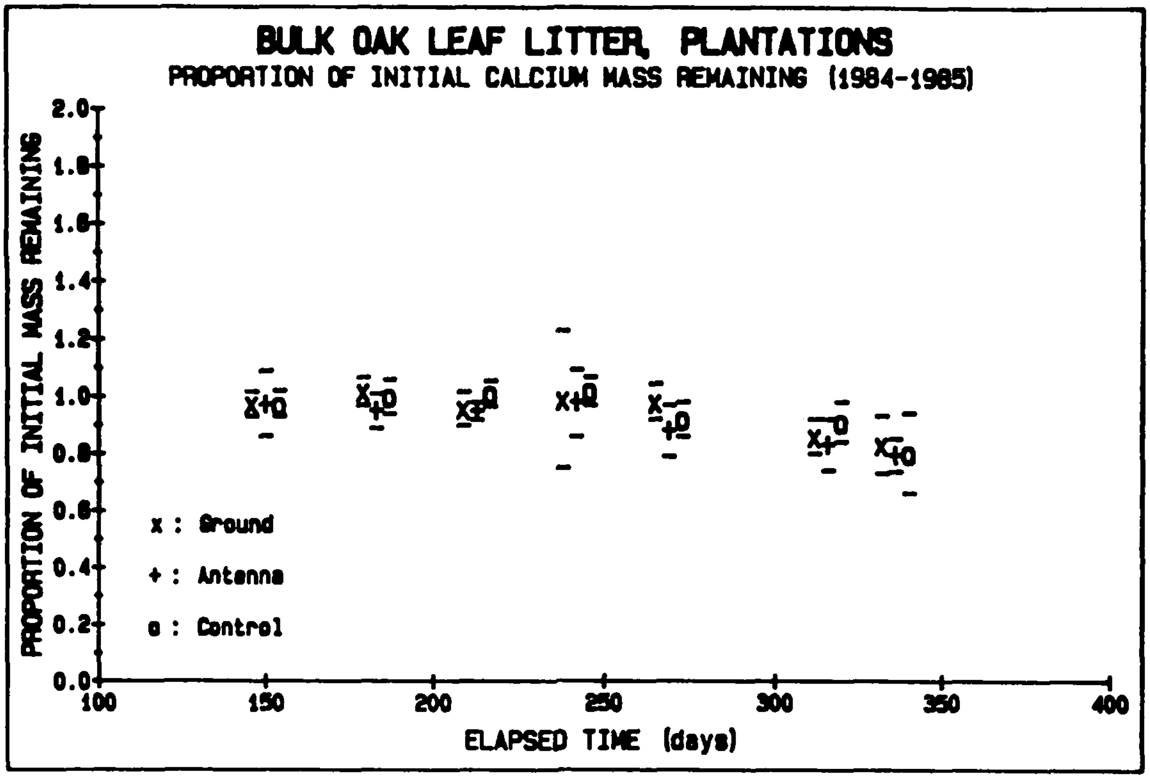

BULK OAK LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL CALCIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 130.


BULK OAK LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL CALCIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

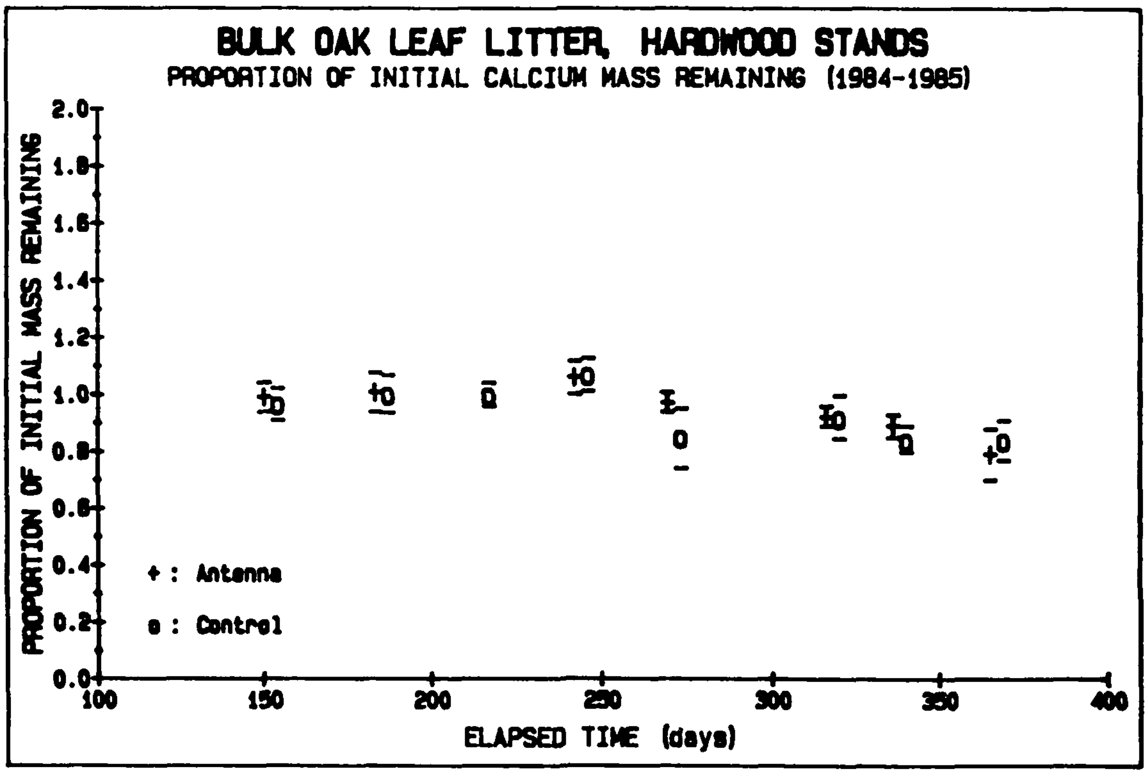

BULK OAK LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL CALCIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 131.

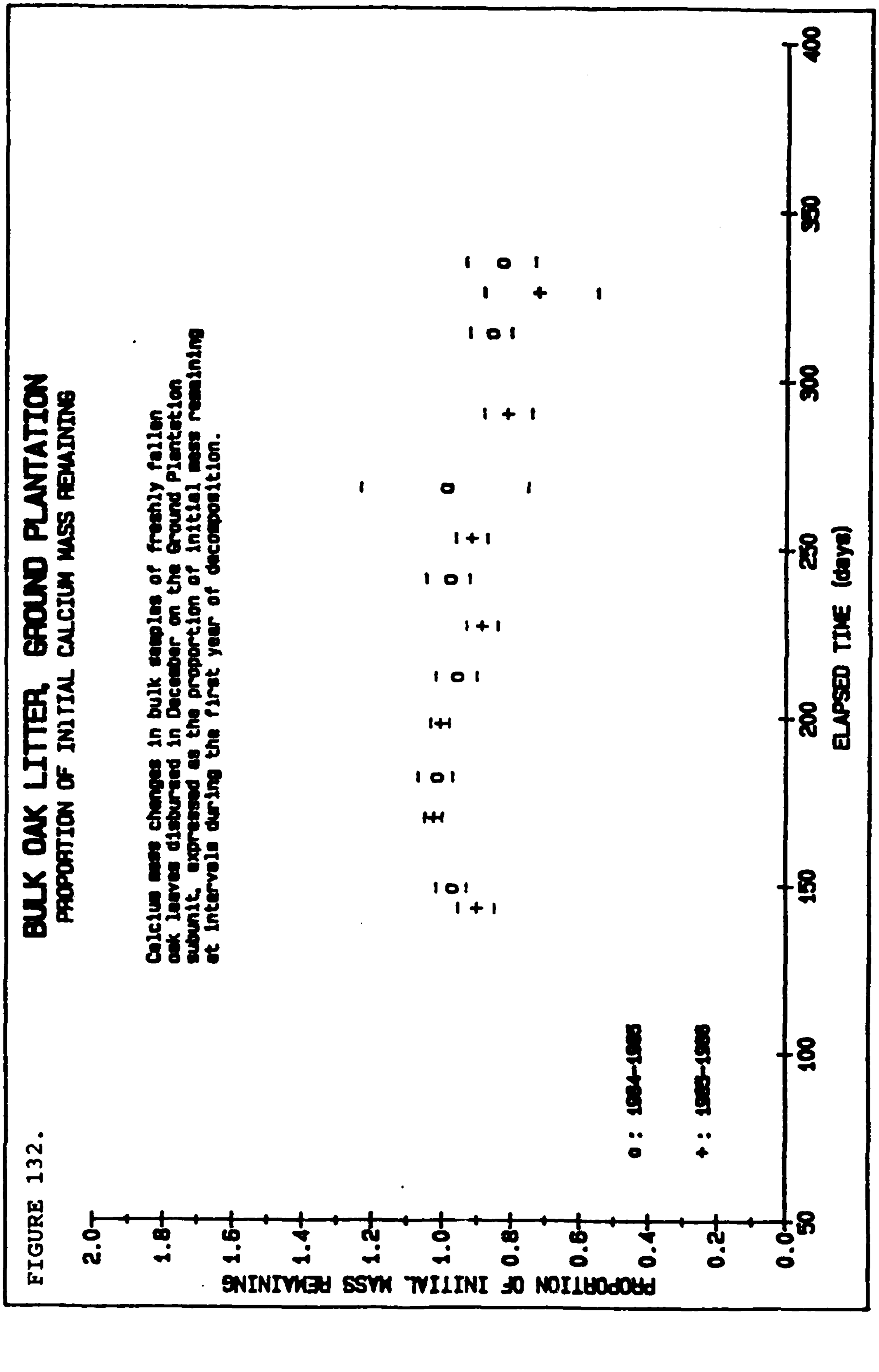


FIGURE 132.
BULK OAK LITTER, GROUND PLANTATION
PROPORTION OF INITIAL CALCIUM MASS REMAINING
Calcium mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Ground Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
o : 1984–1985
+ : 1985–1986
PROPORTION OF INITIAL MASS REMAINING
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 133.

BULK OAK LITTER, ANTENNA PLANTATION

PROPORTION OF INITIAL CALCIUM MASS REMAINING

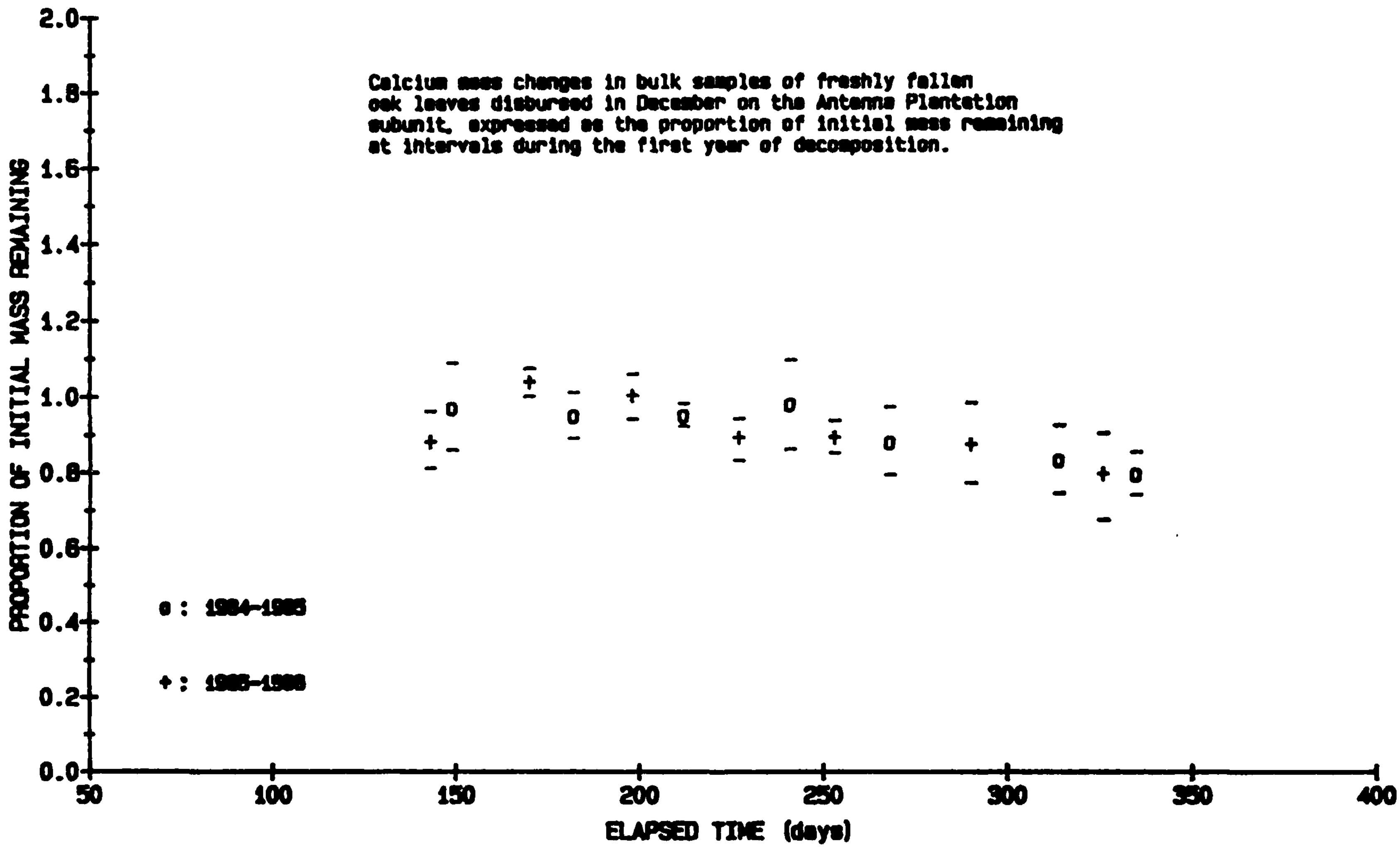


FIGURE 134.

BULK OAK LITTER, CONTROL PLANTATION

PROPORTION OF INITIAL CALCIUM MASS REMAINING

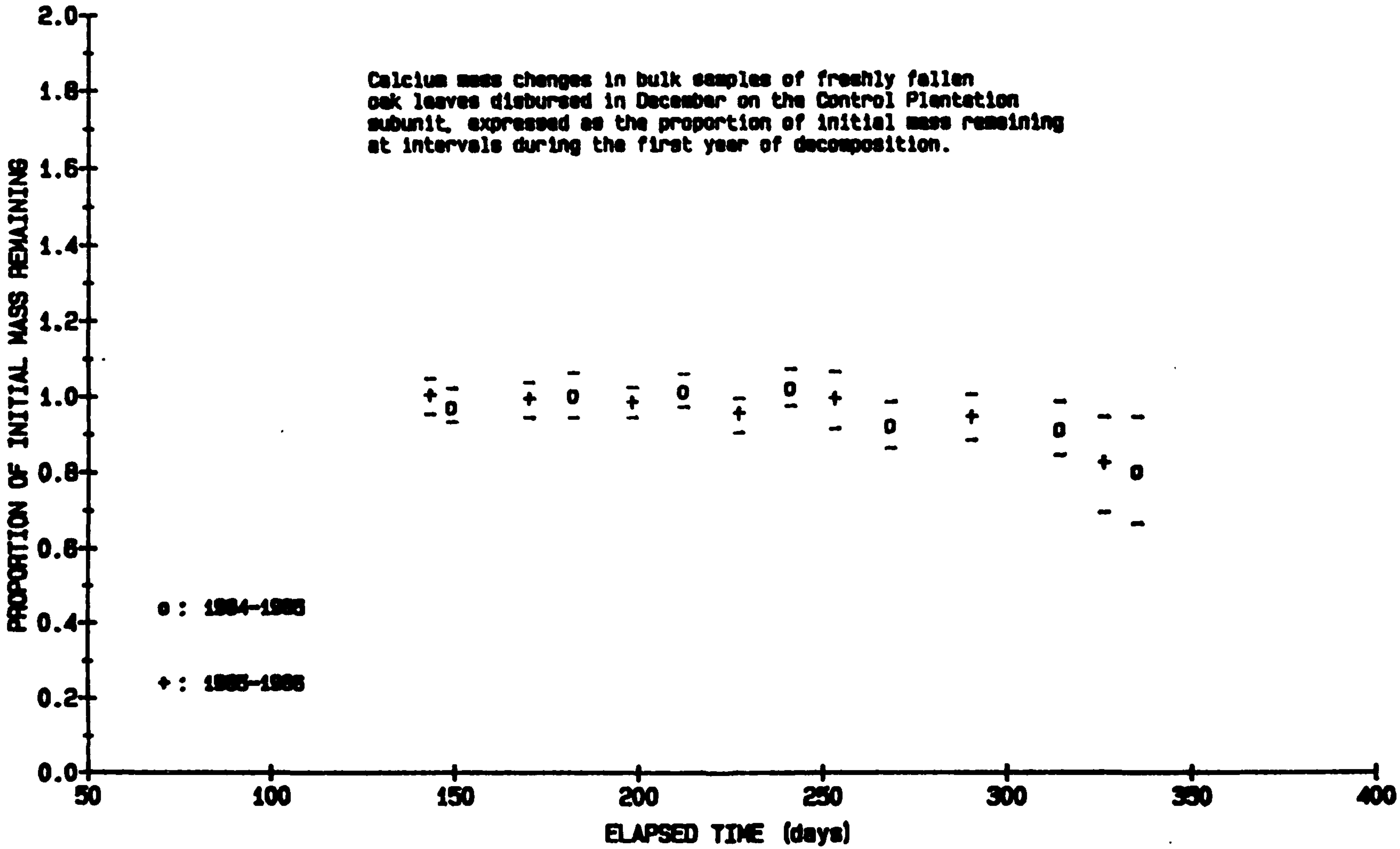


FIGURE 135.

BULK OAK LITTER, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL CALCIUM MASS REMAINING

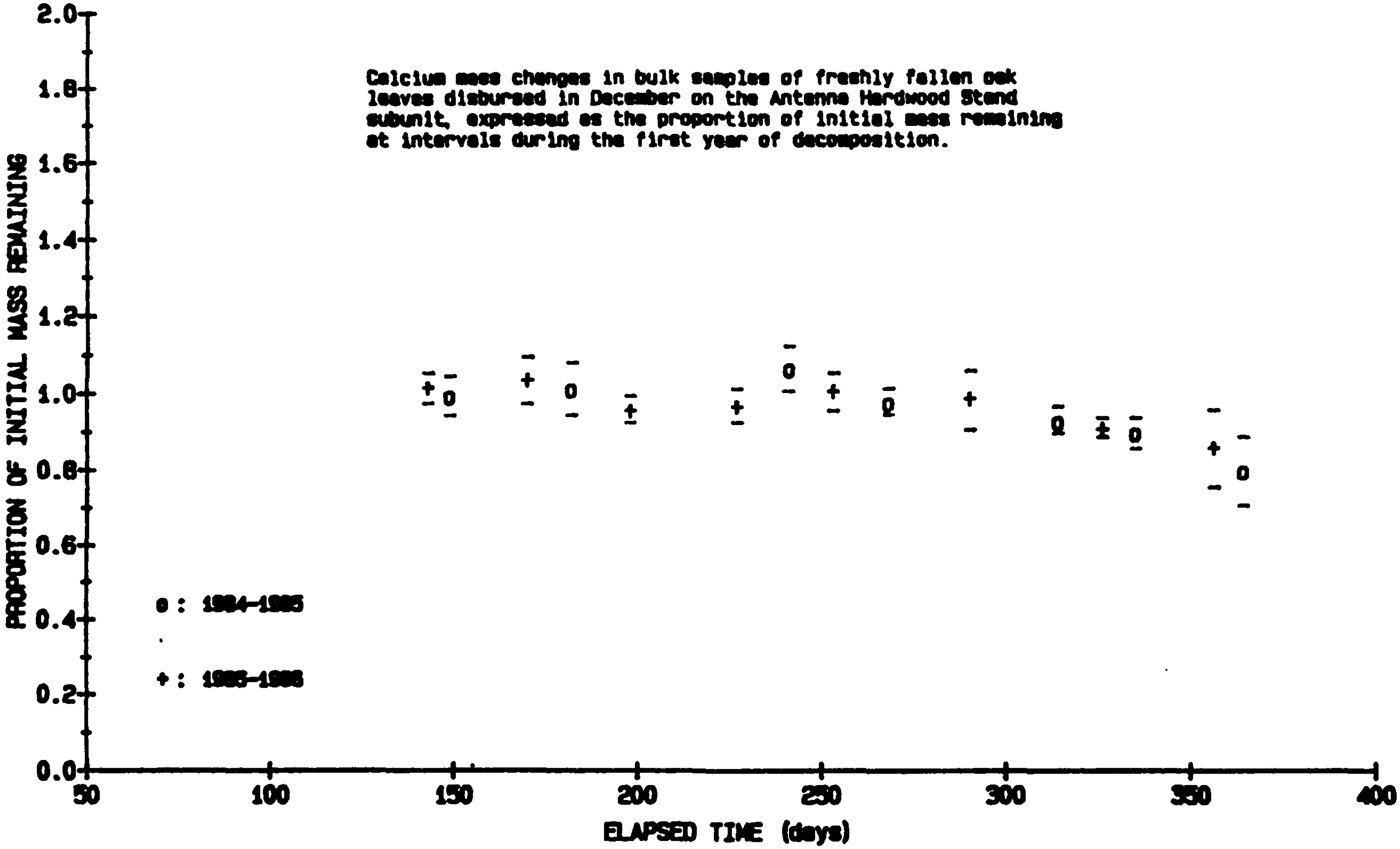
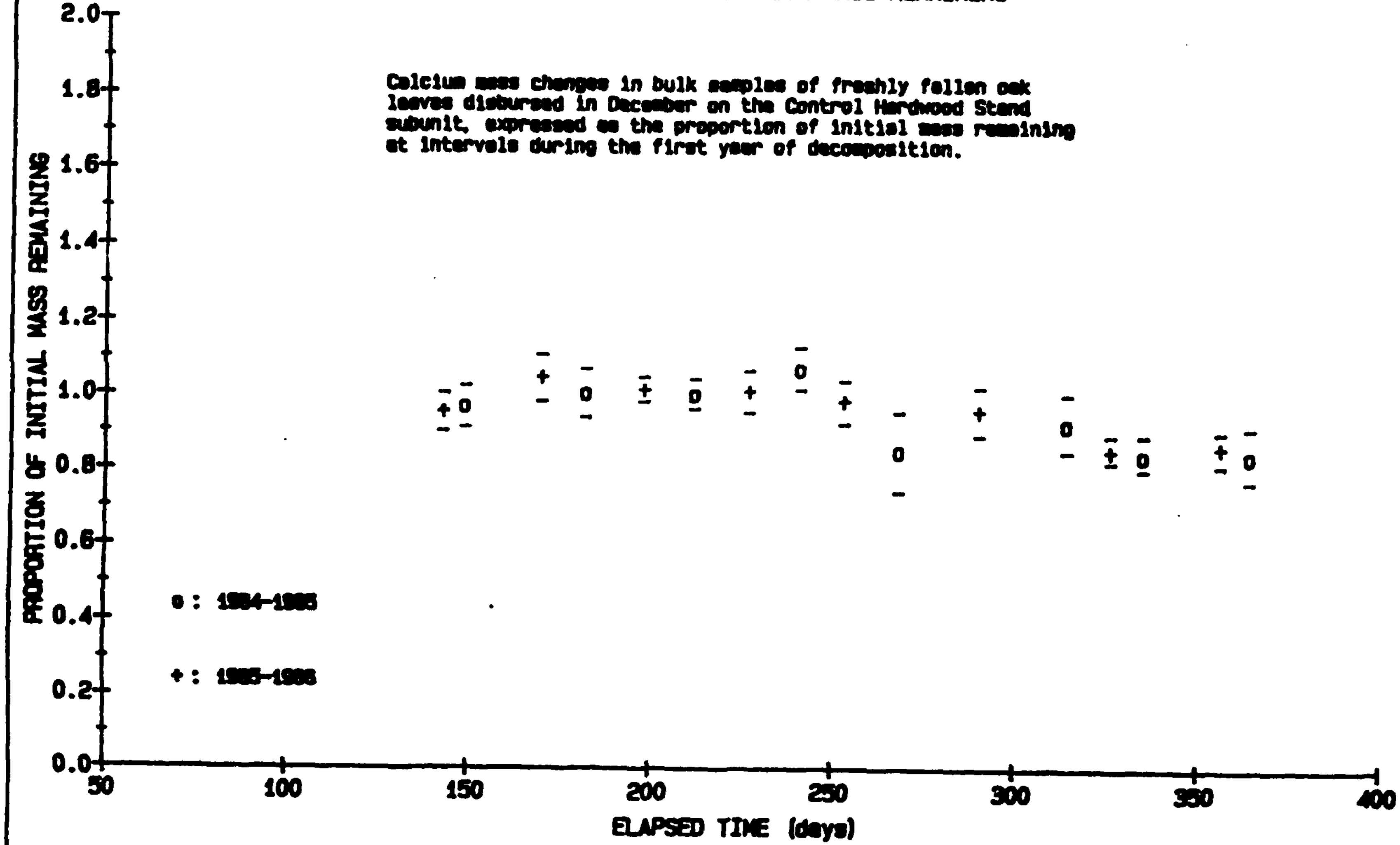
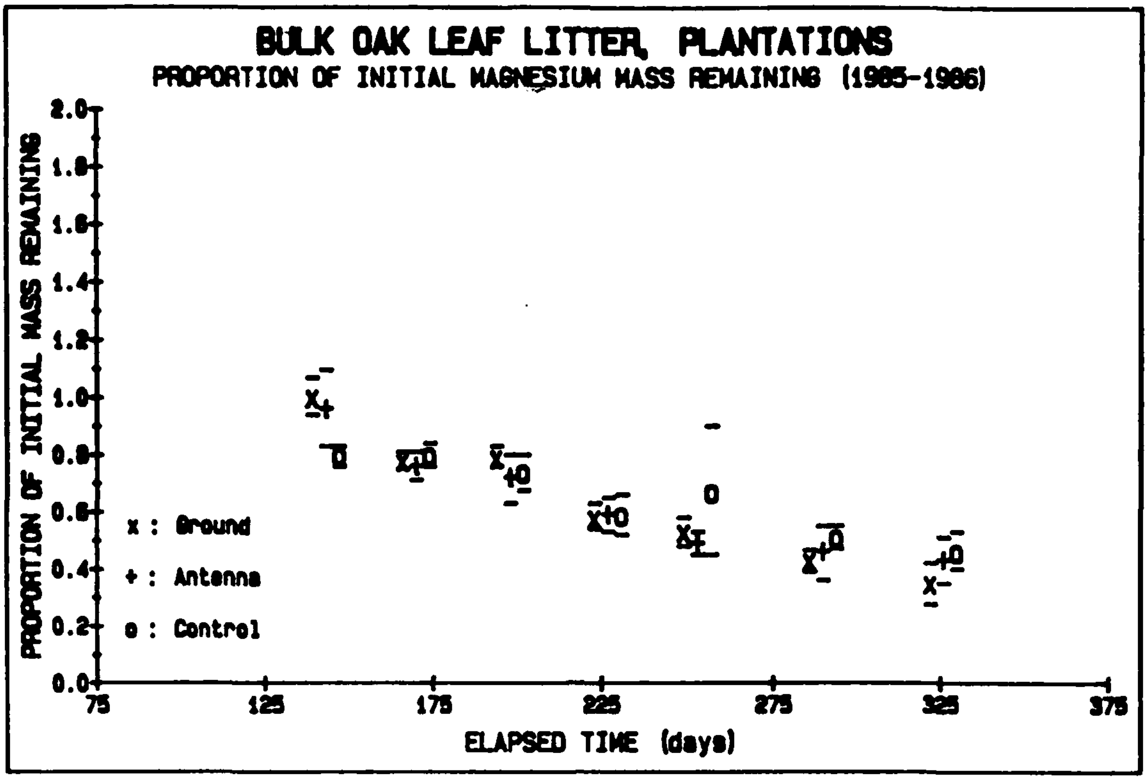


FIGURE 136.

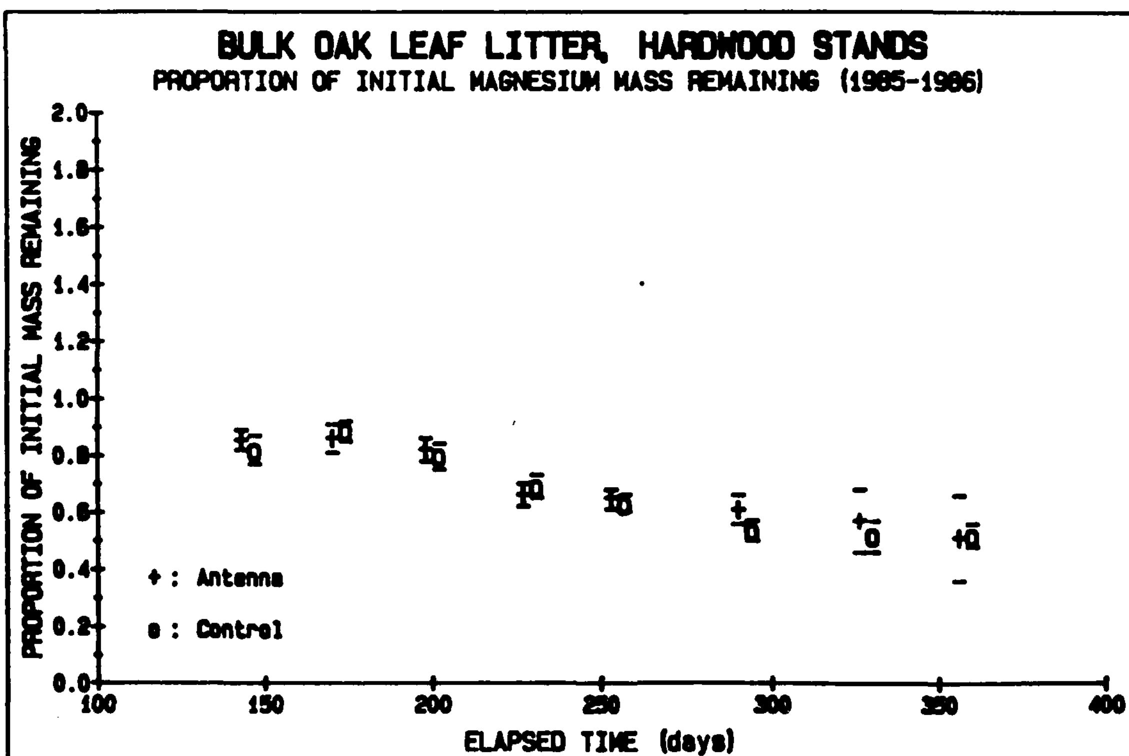
BULK OAK LITTER, CONTROL HARDWOOD STAND
PROPORTION OF INITIAL CALCIUM MASS REMAINING

Calcium mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Control Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.



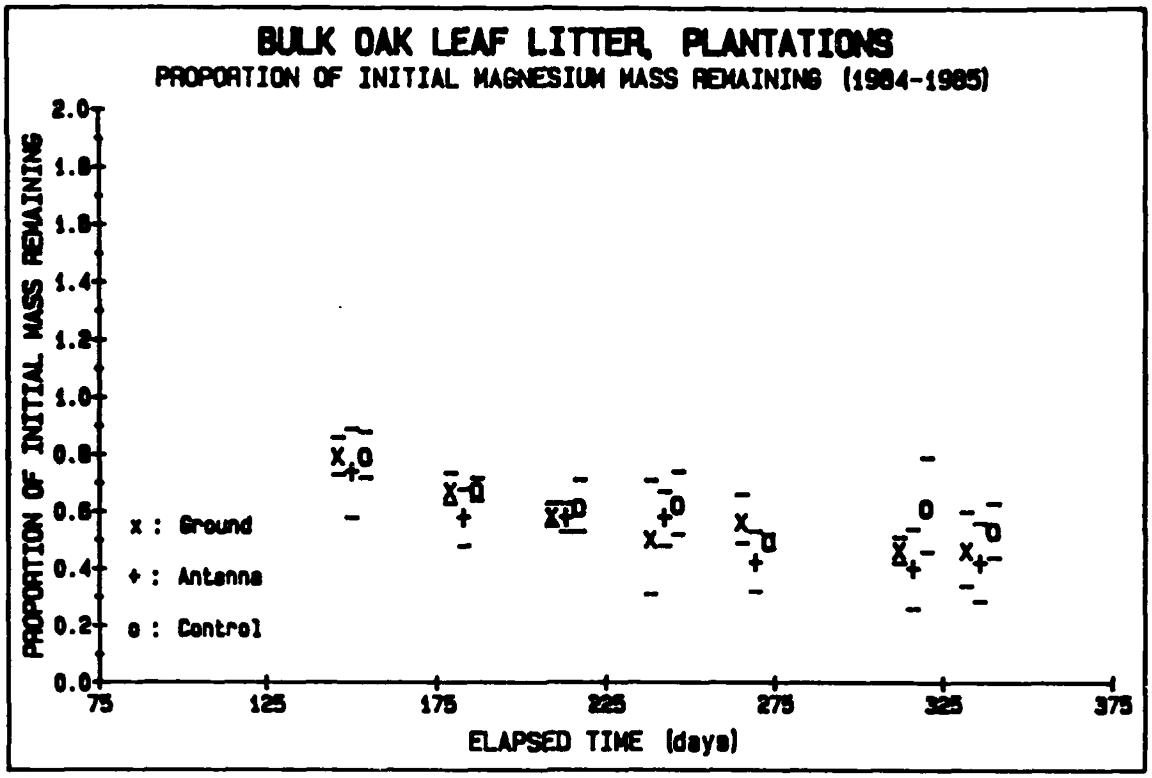


BULK OAK LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control



BULK OAK LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
+ : Antenna
o : Control

FIGURE 137.


BULK OAK LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
x : Ground
+ : Antenna
o : Control
ELAPSED TIME (days)

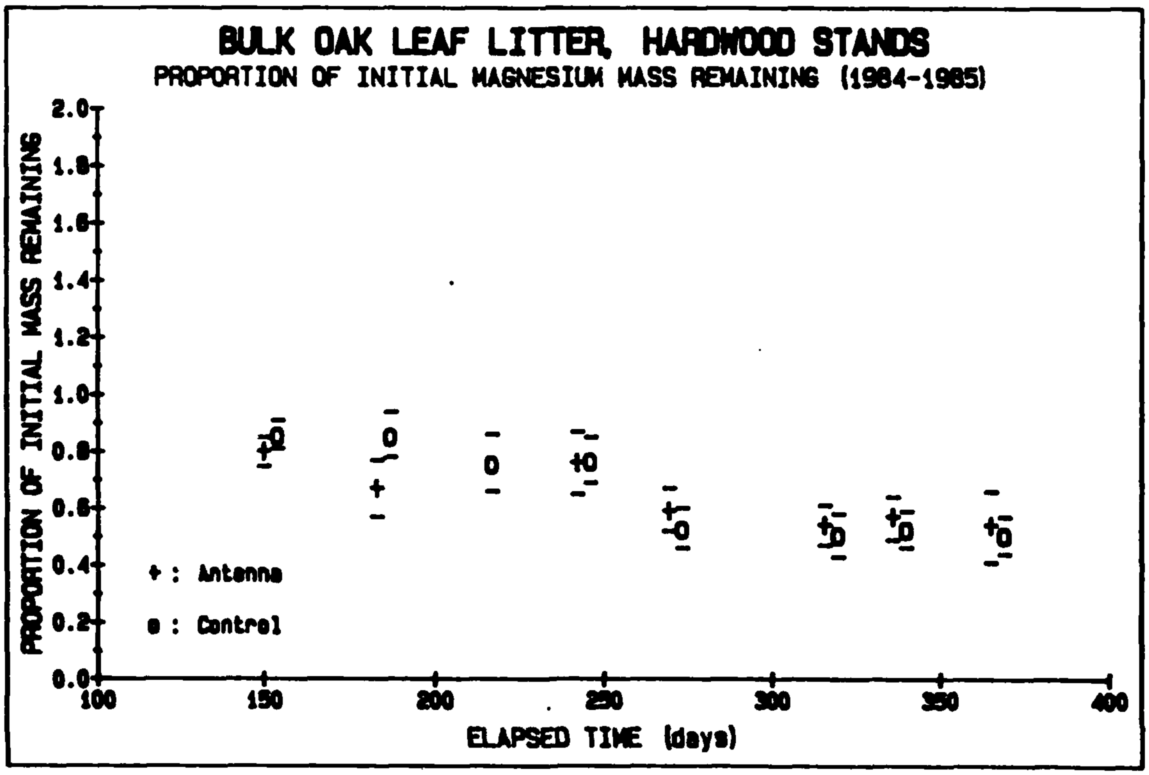

BULK OAK LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
+ : Antenna
o : Control
ELAPSED TIME (days)

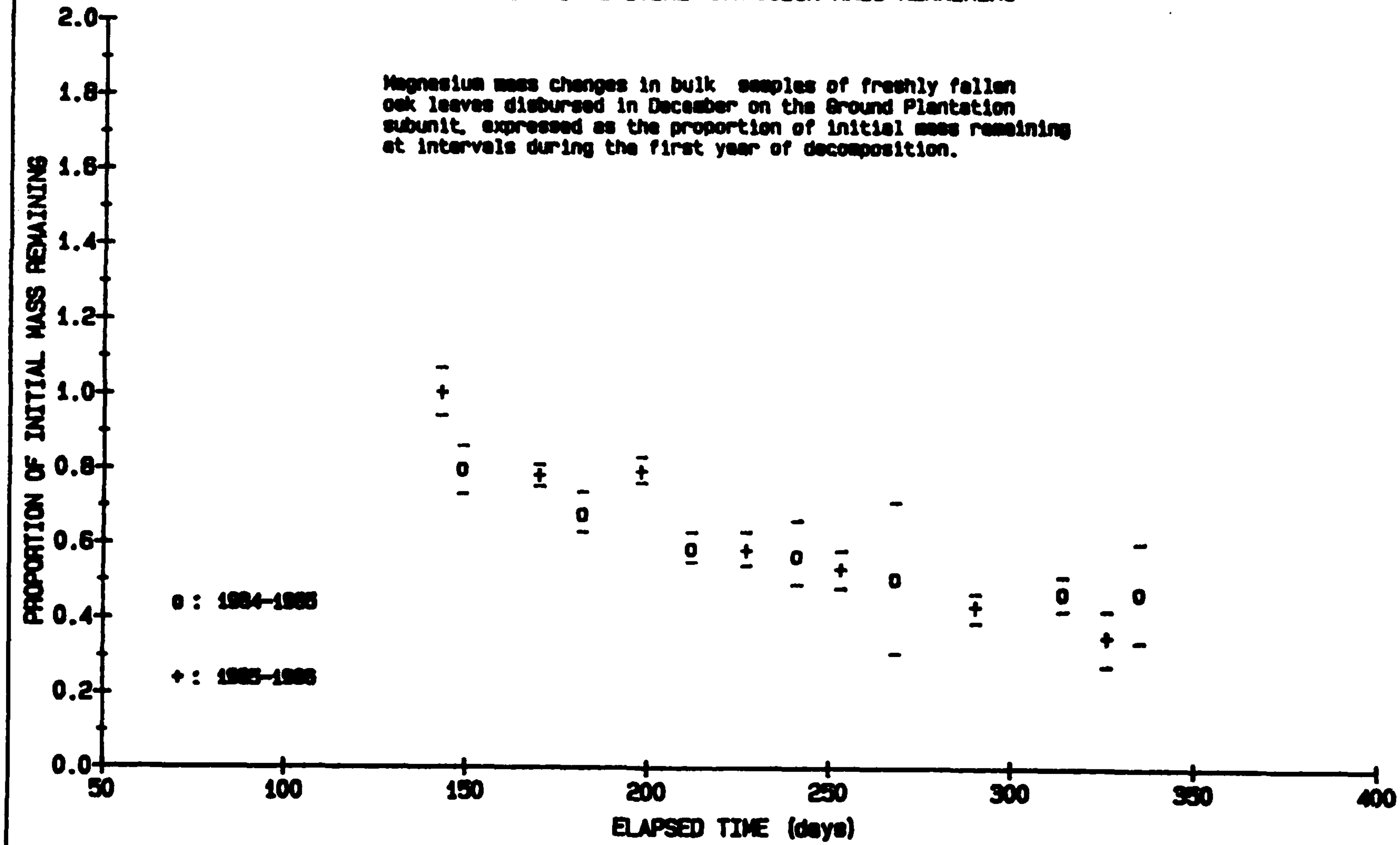
FIGURE 138.

FIGURE 139.

BULK OAK LITTER, GROUND PLANTATION

PROPORTION OF INITIAL MAGNESIUM MASS REMAINING

Magnesium mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Ground Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.



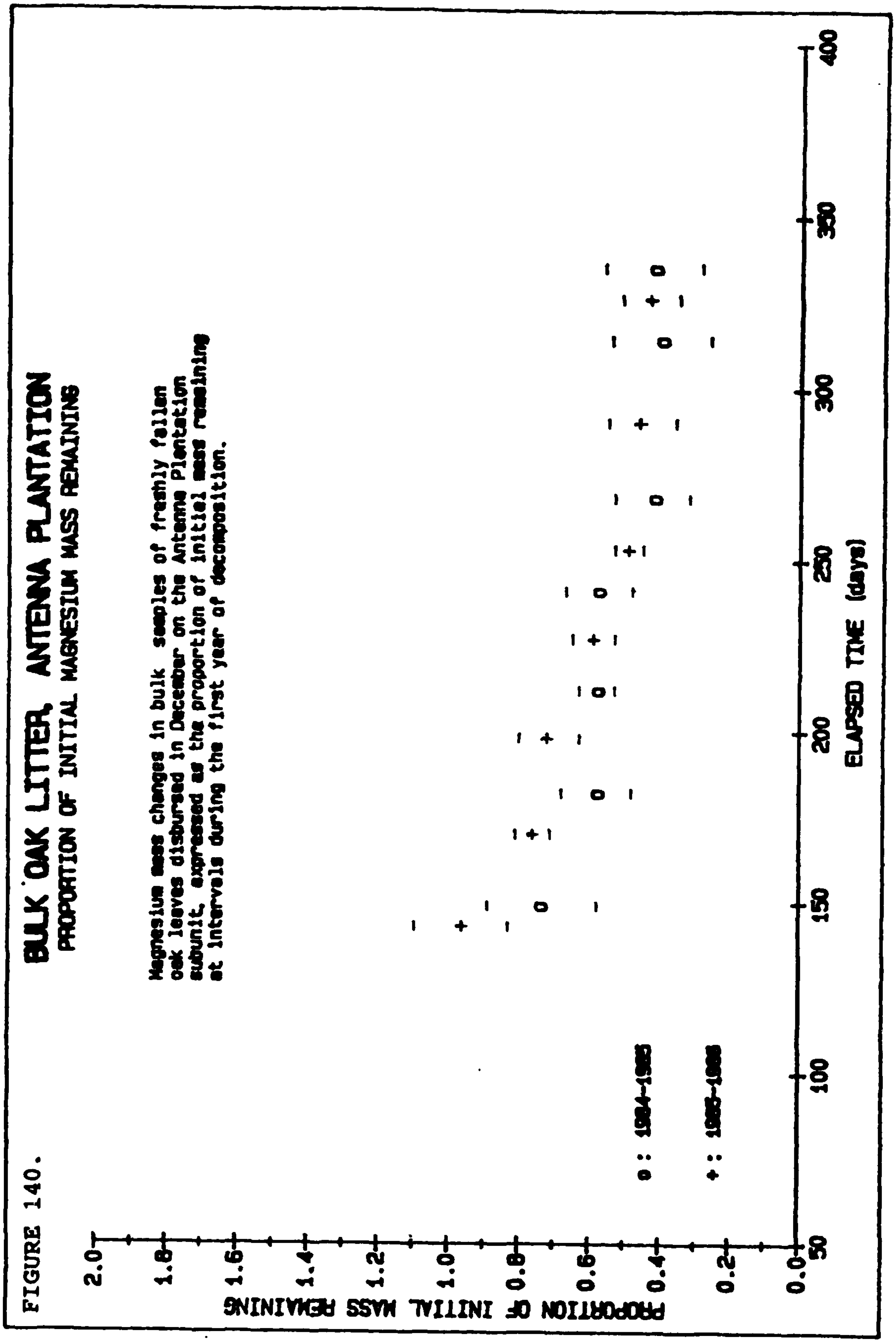

BULK OAK LITTER, ANTENNA PLANTATION
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING
Magnesium mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Antenna Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
o: 1984-1985
+: 1985-1986
PROPORTION OF INITIAL MASS REMAINING
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 140.

FIGURE 141.

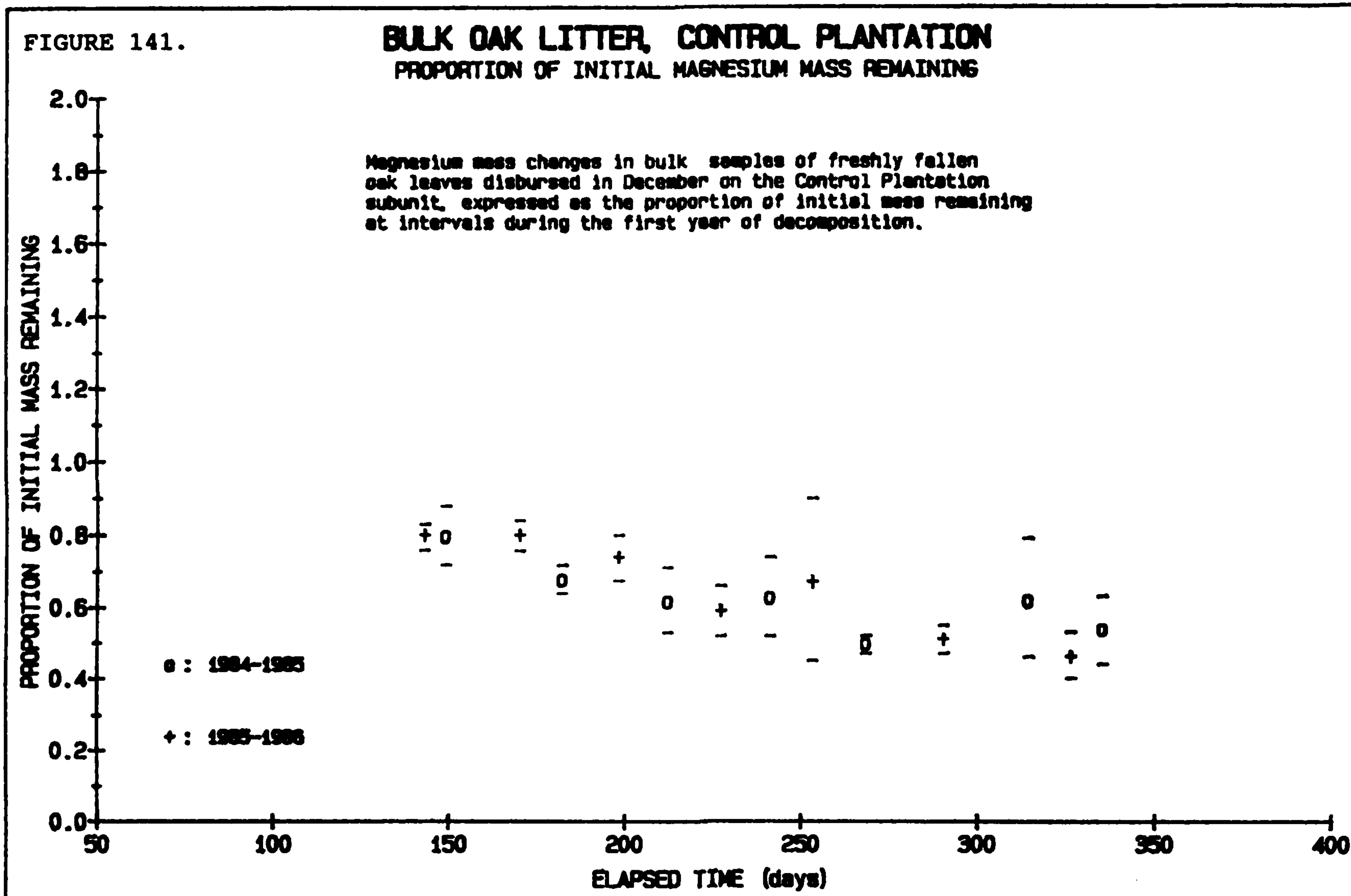

BULK OAK LITTER, CONTROL PLANTATION
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING
Magnesium mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Control Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
o : 1984-1985
+ : 1985-1986
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 142.

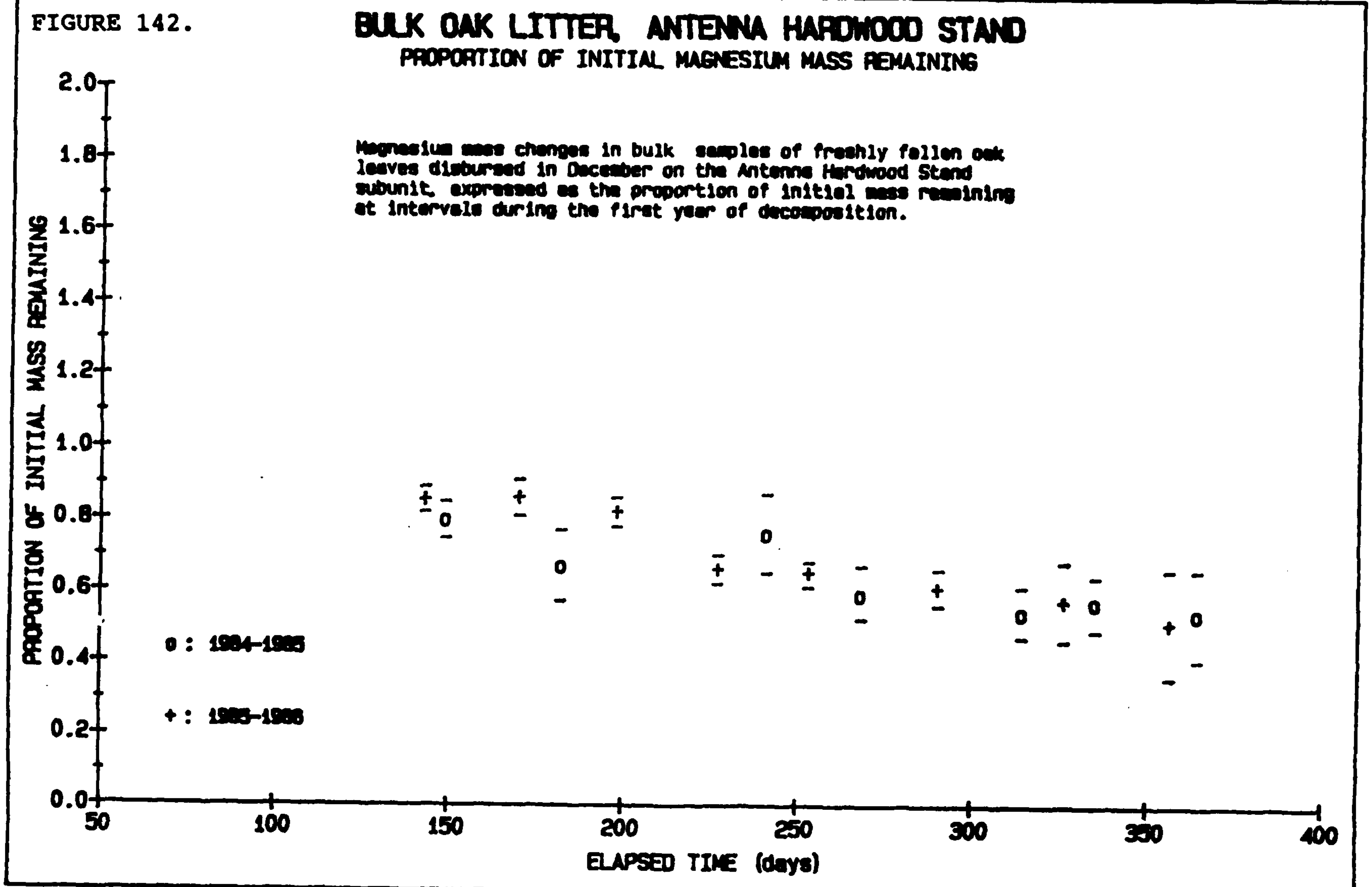
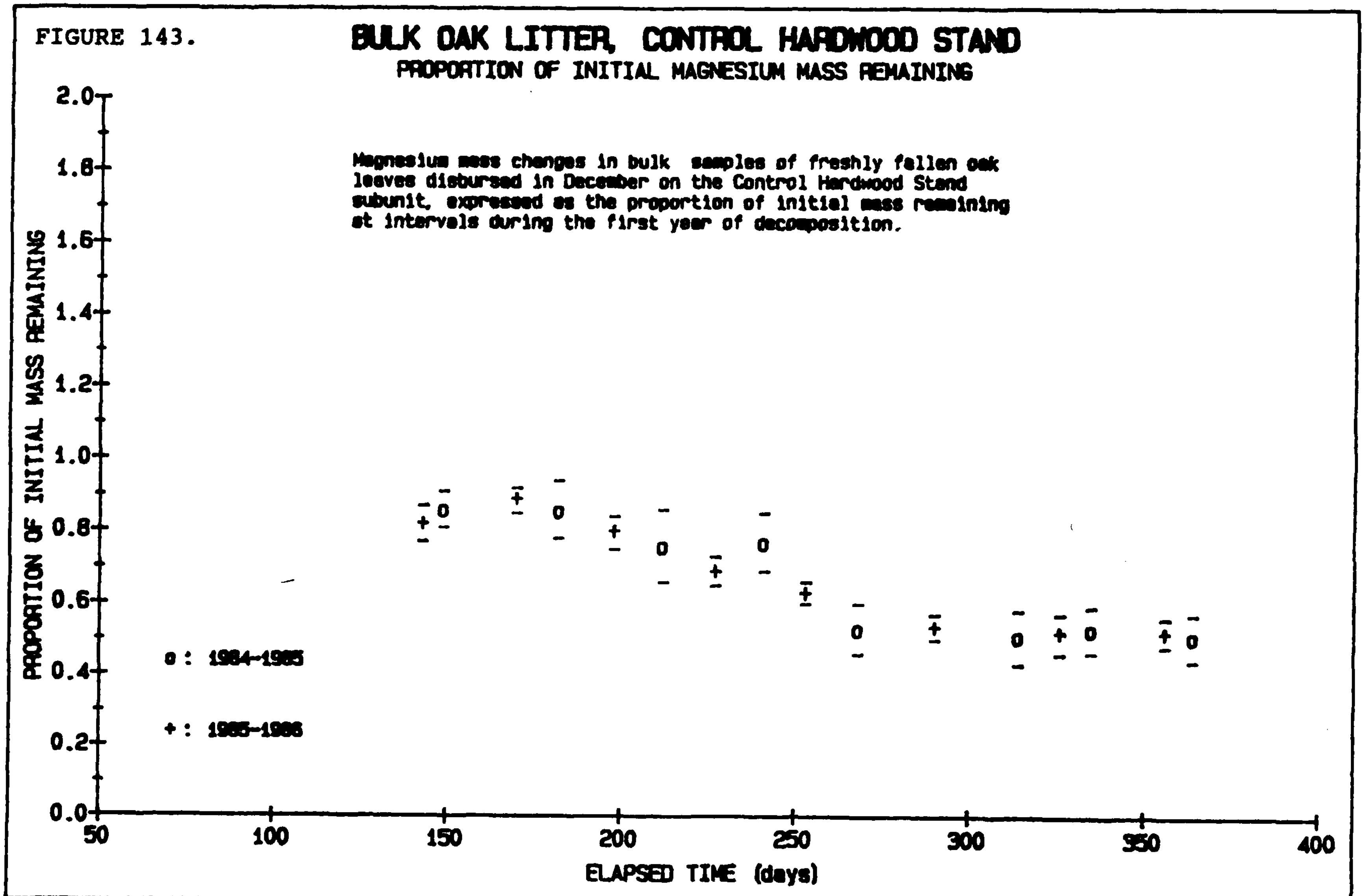
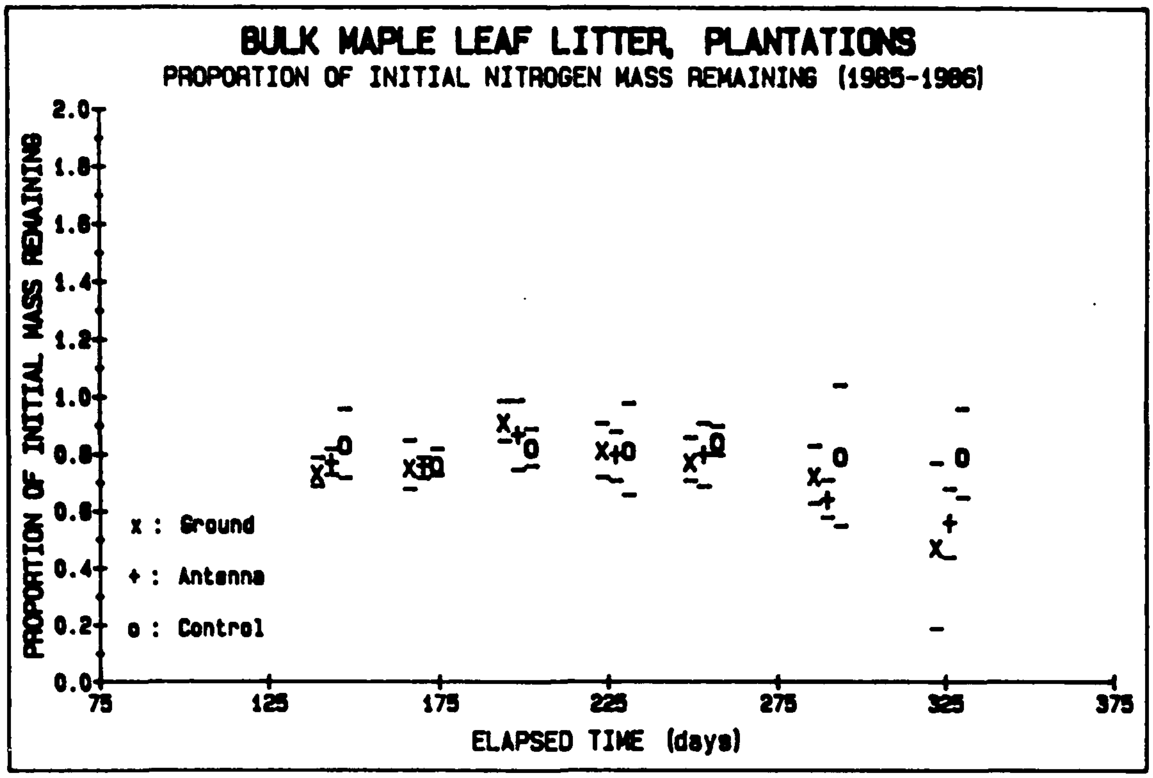

BULK OAK LITTER, ANTENNA HARDWOOD STAND
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING
Magnesium mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Antenna Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
o : 1984-1985
+ : 1985-1986
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 143.


BULK OAK LITTER, CONTROL HARDWOOD STAND
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING
Magnesium mass changes in bulk samples of freshly fallen oak leaves disbursed in December on the Control Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
o : 1984-1985
+ : 1985-1986
50
100
150
200
250
300
350
400
ELAPSED TIME (days)


BULK MAPLE LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL NITROGEN MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
75
125
175
225
275
325
375
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control

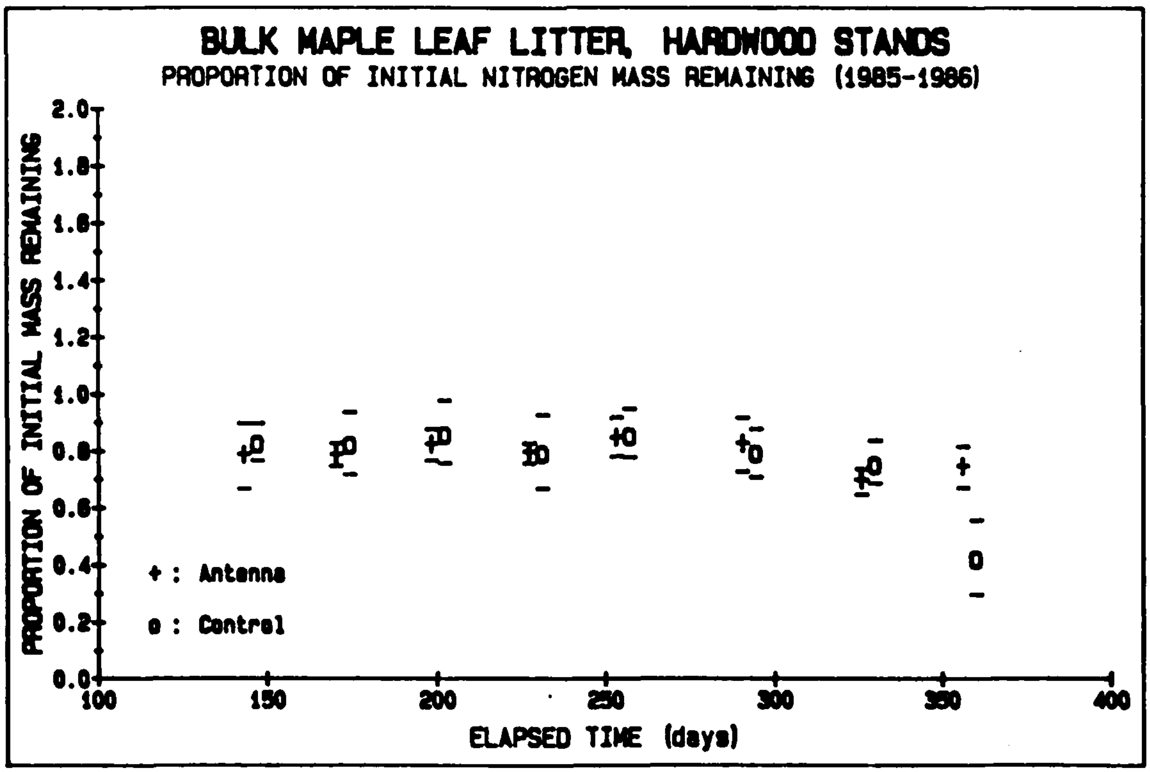
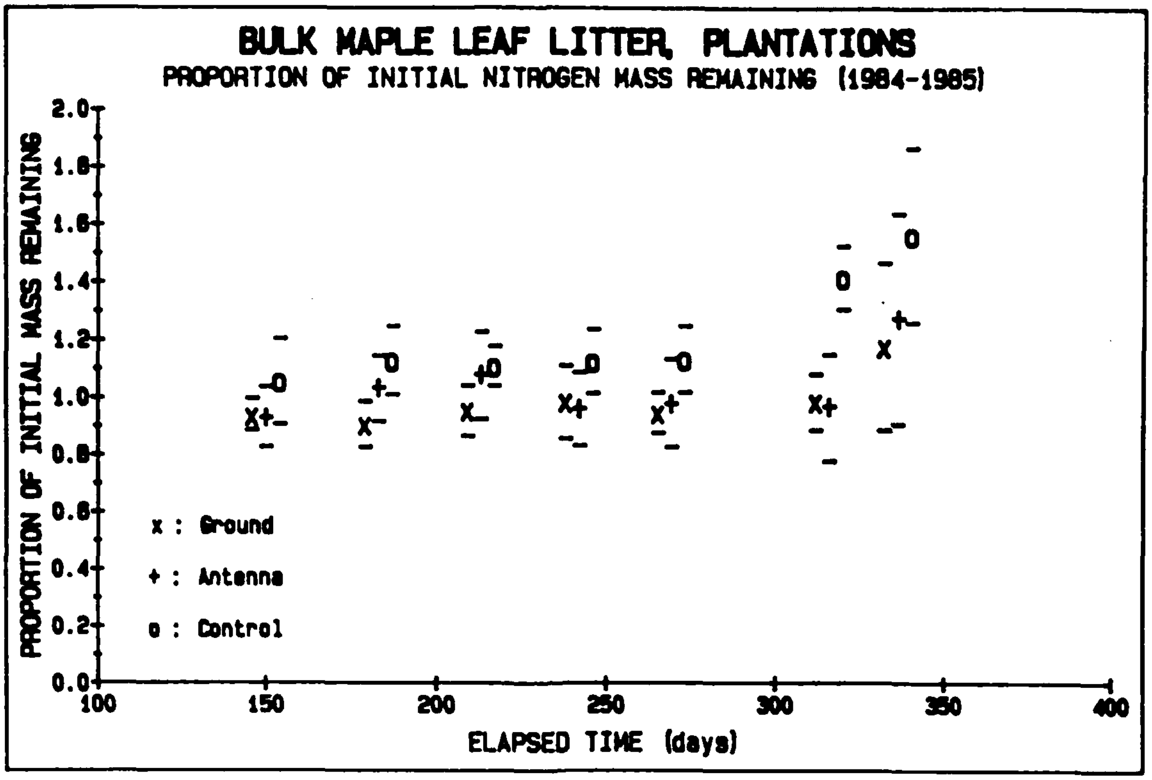

BULK MAPLE LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL NITROGEN MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
100
150
200
250
300
350
400
ELAPSED TIME (days)
+ : Antenna
o : Control

FIGURE 144.


BULK MAPLE LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL NITROGEN MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
100
150
200
250
300
350
400

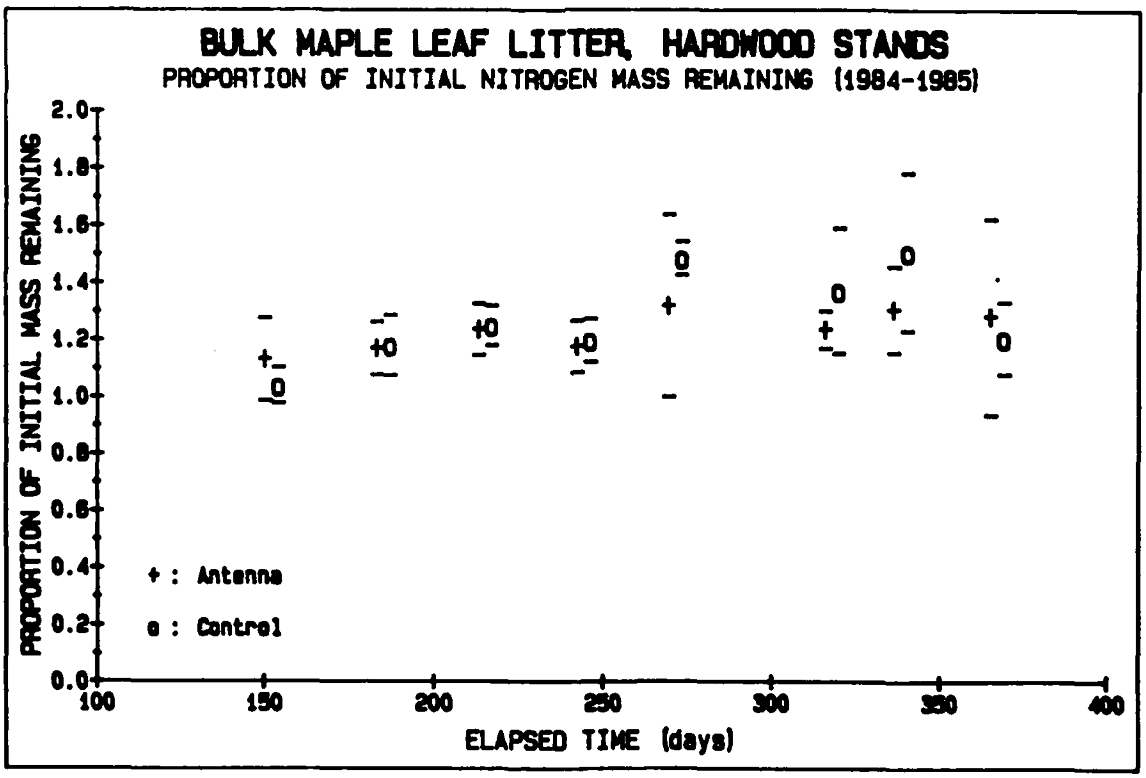

BULK MAPLE LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL NITROGEN MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
+ : Antenna
o : Control
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
100
150
200
250
300
350
400

FIGURE 145.

FIGURE 146.

BULK MAPLE LITTER, GROUND PLANTATION

PROPORTION OF INITIAL NITROGEN MASS REMAINING

Nitrogen mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Ground Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

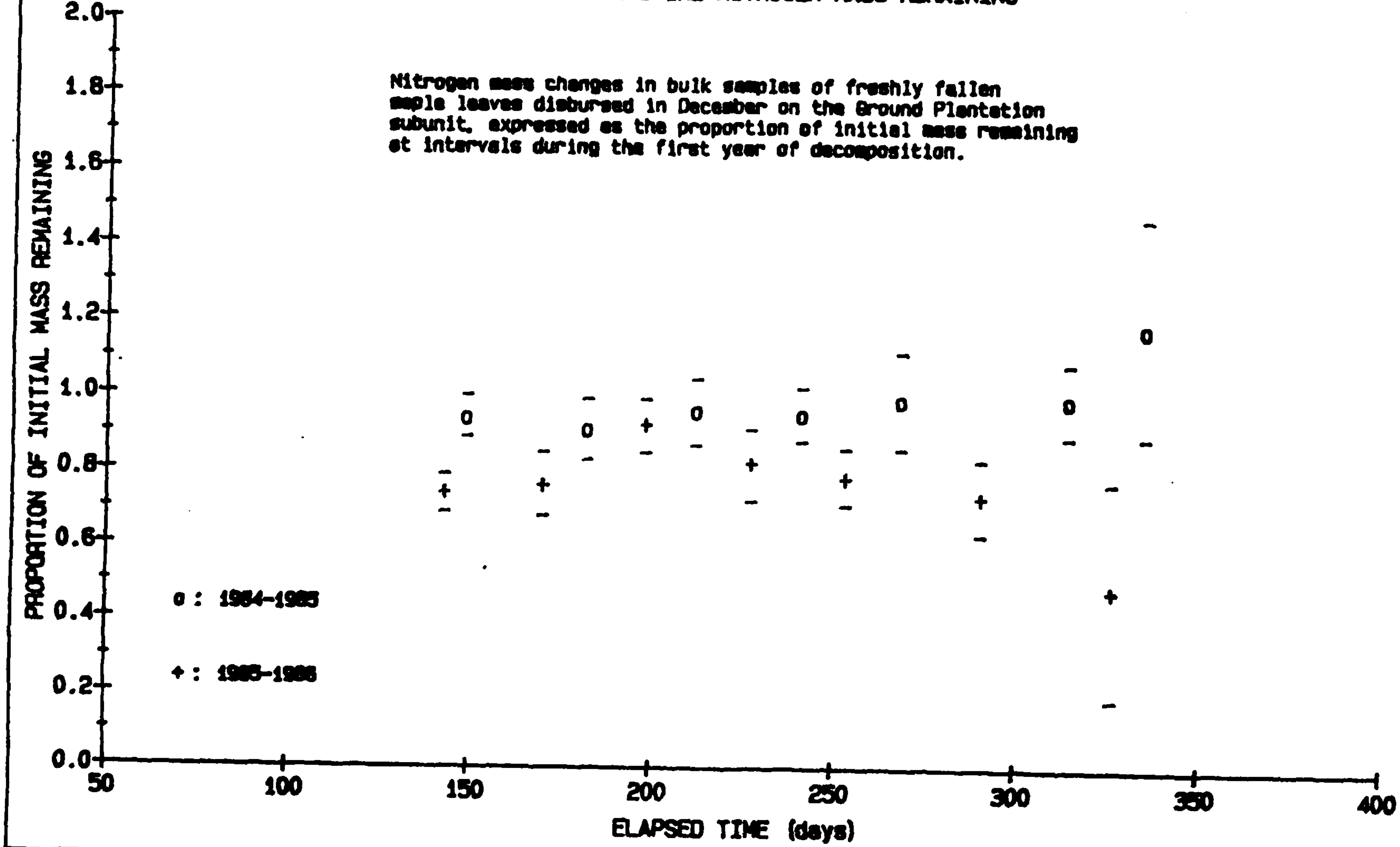


FIGURE 147.

BULK MAPLE LITTER, ANTENNA PLANTATION
PROPORTION OF INITIAL NITROGEN MASS REMAINING

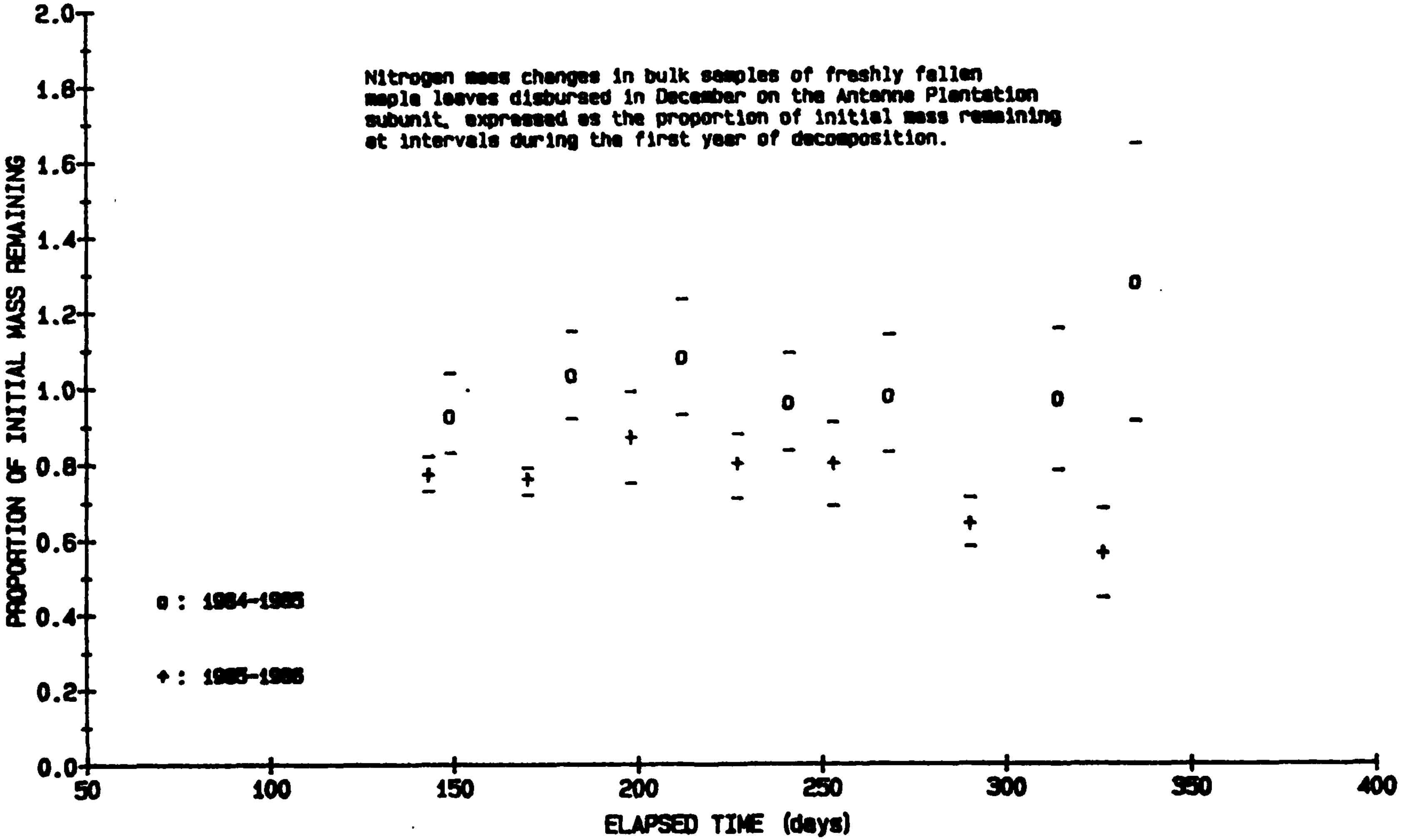
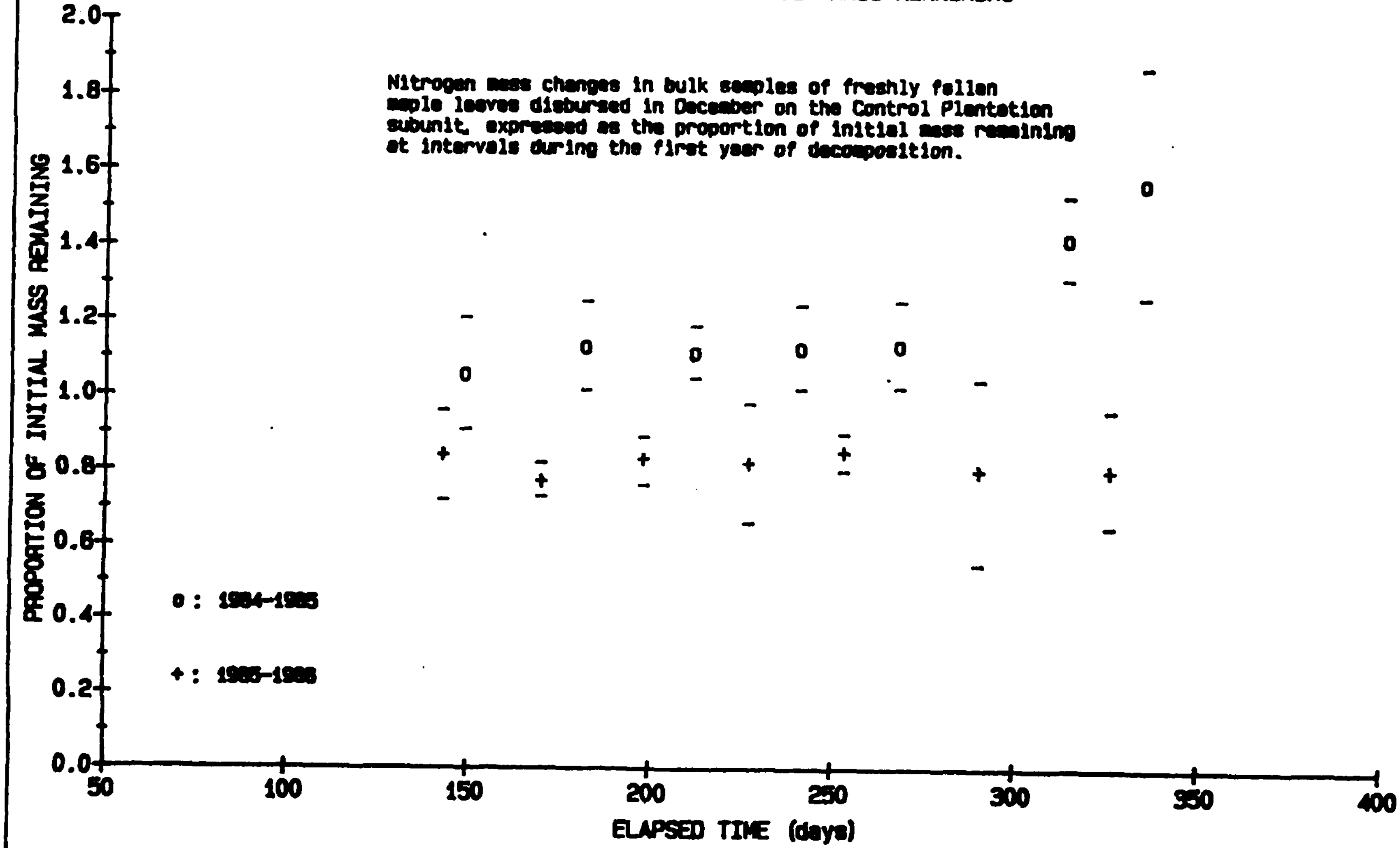


FIGURE 148.

BULK MAPLE LITTER, CONTROL PLANTATION

PROPORTION OF INITIAL NITROGEN MASS REMAINING



Nitrogen mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Control Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

FIGURE 149.

BULK MAPLE LITTER, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL NITROGEN MASS REMAINING

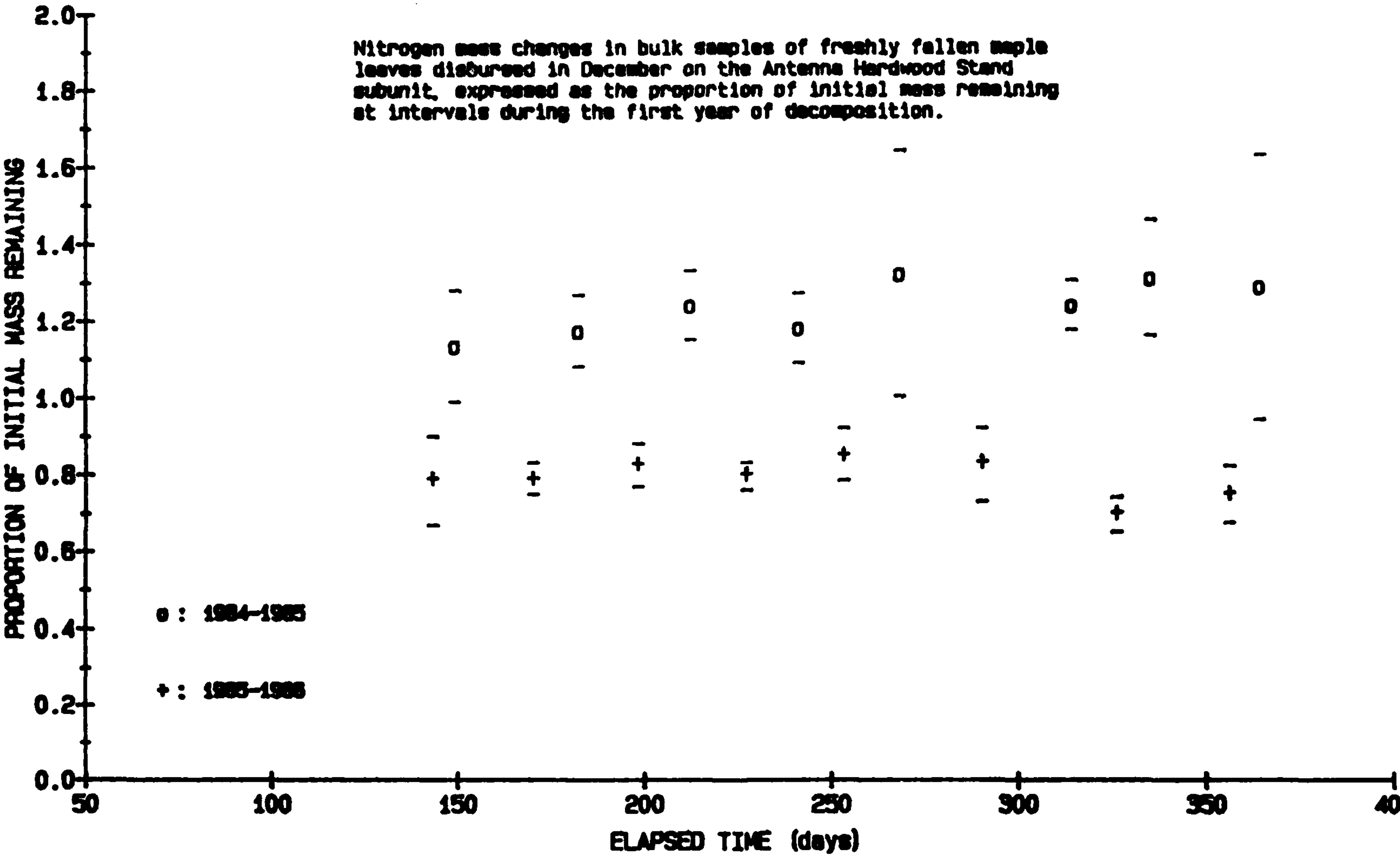
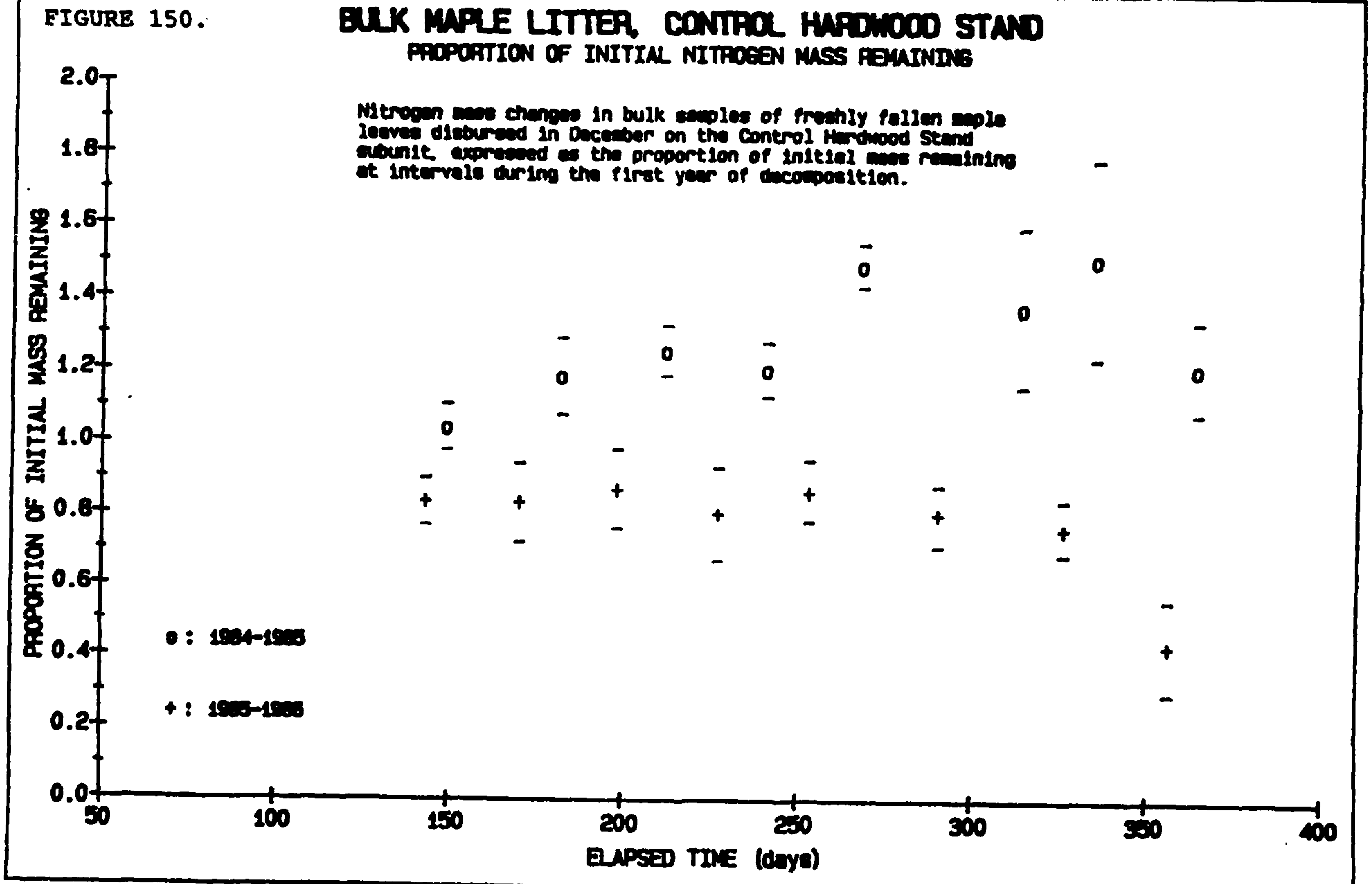
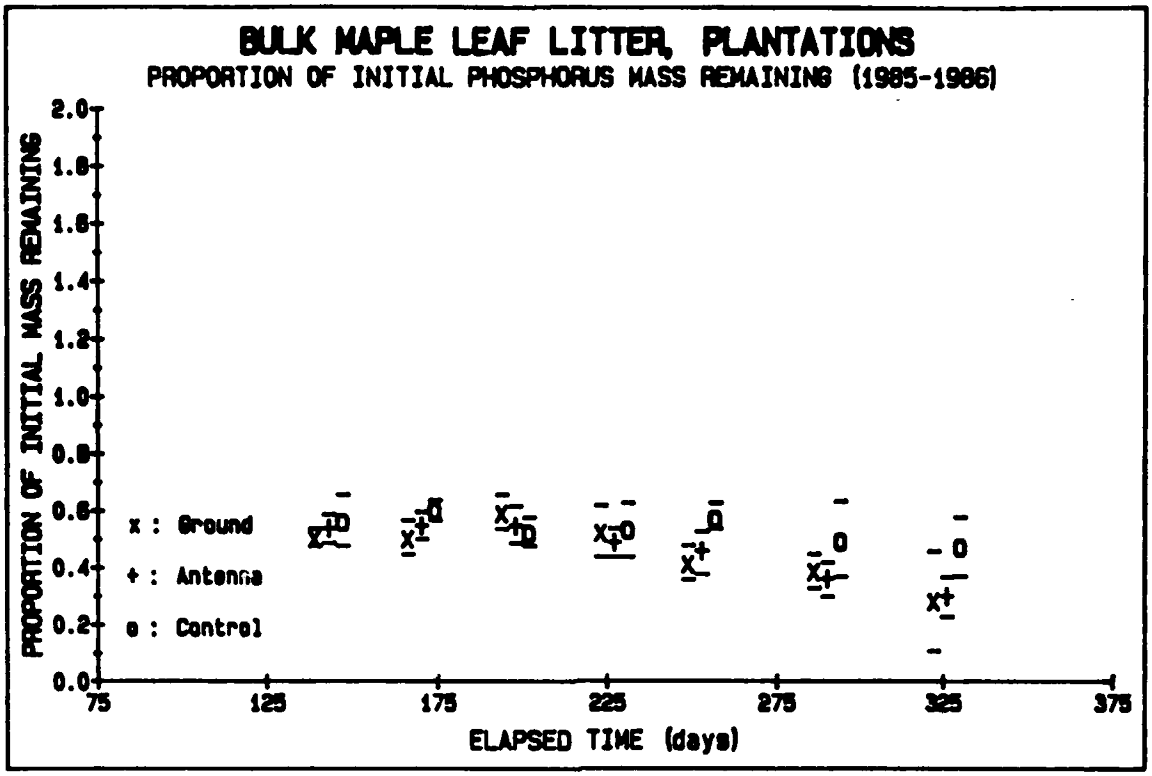


FIGURE 150.


BULK MAPLE LITTER, CONTROL HARDWOOD STAND
PROPORTION OF INITIAL NITROGEN MASS REMAINING
Nitrogen mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Control Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
o : 1984-1985
+ : 1985-1986
50
100
150
200
250
300
350
400
ELAPSED TIME (days)


BULK MAPLE LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
x : Ground
+ : Antenna
o : Control

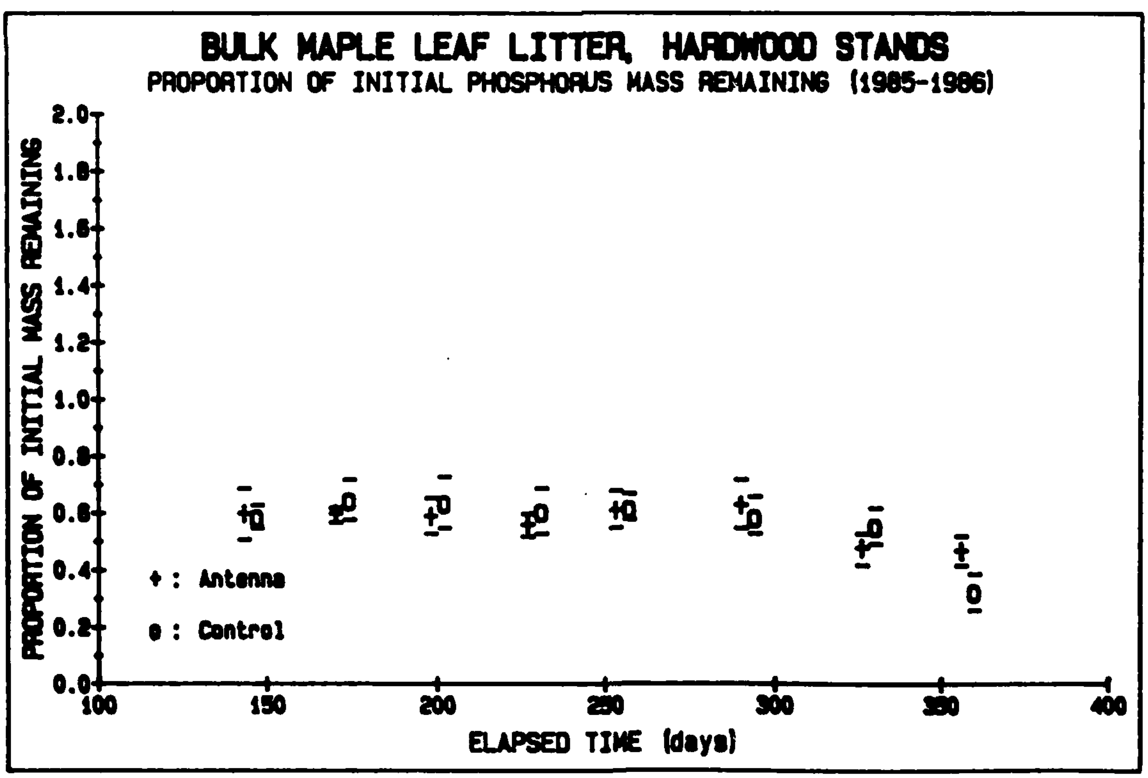
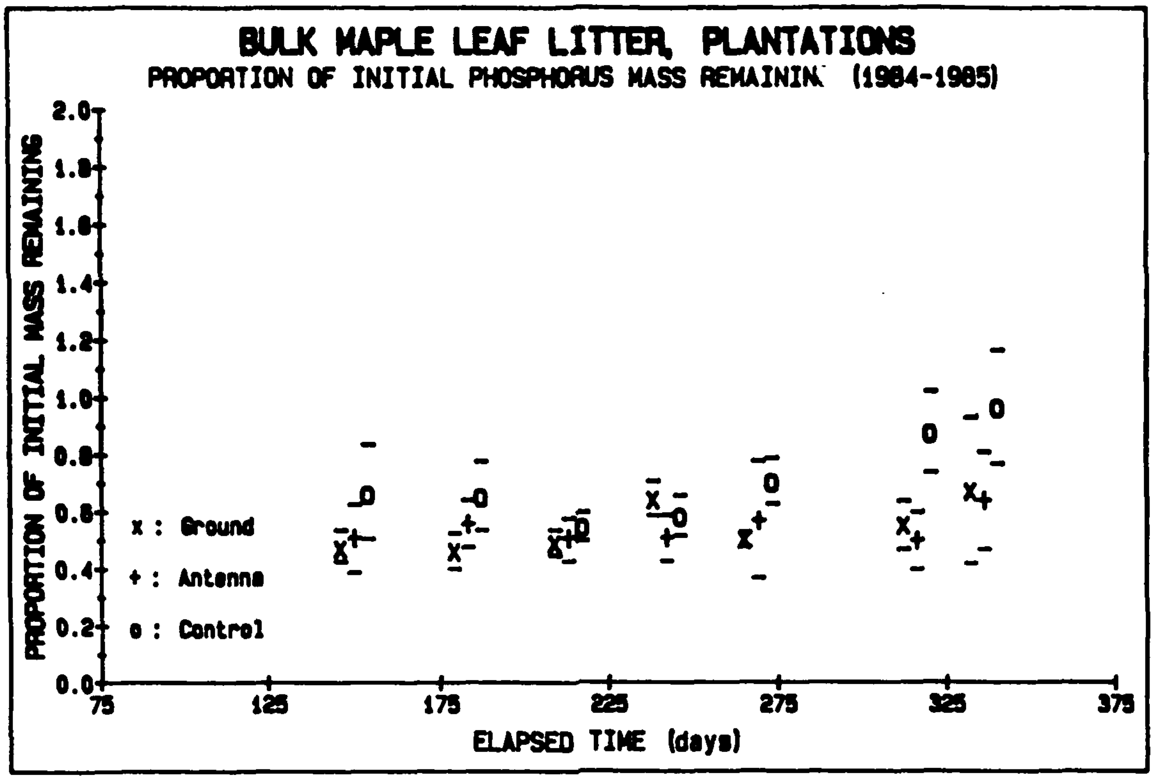

BULK MAPLE LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
ELAPSED TIME (days)
+ : Antenna
o : Control

FIGURE 151.


BULK MAPLE LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

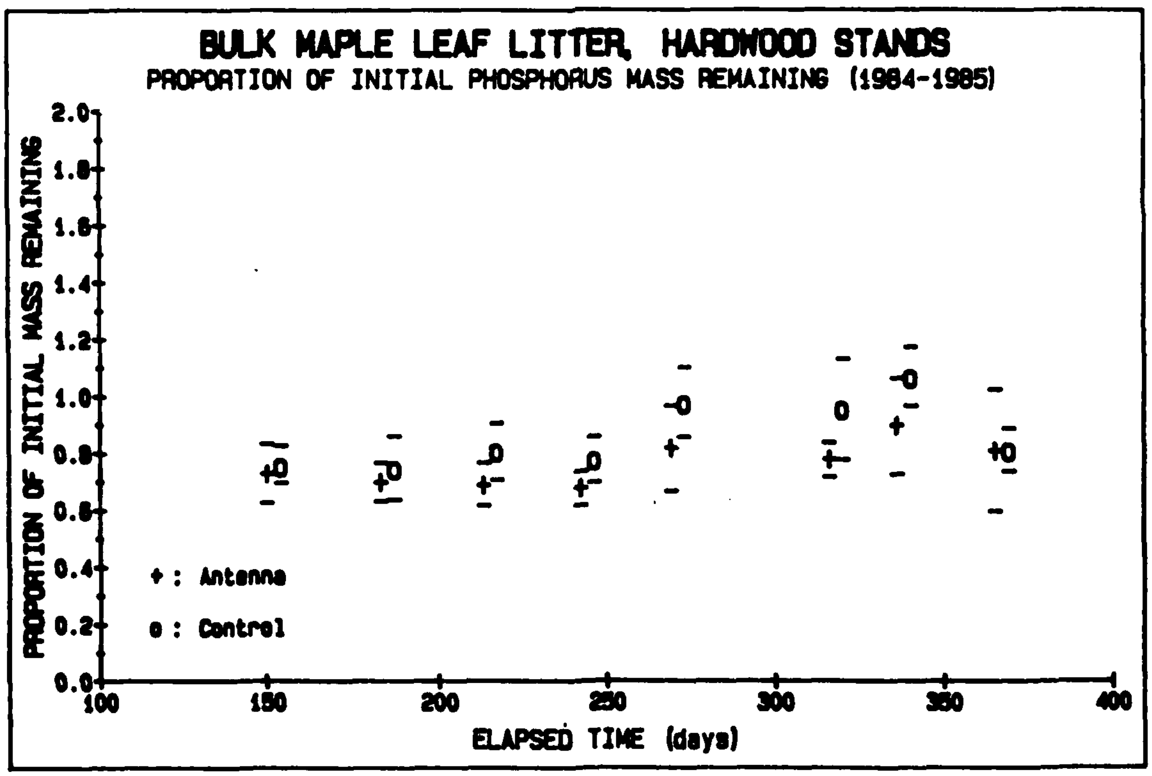

BULK MAPLE LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 152.

FIGURE 153.

BULK MAPLE LITTER, GROUND PLANTATION

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING

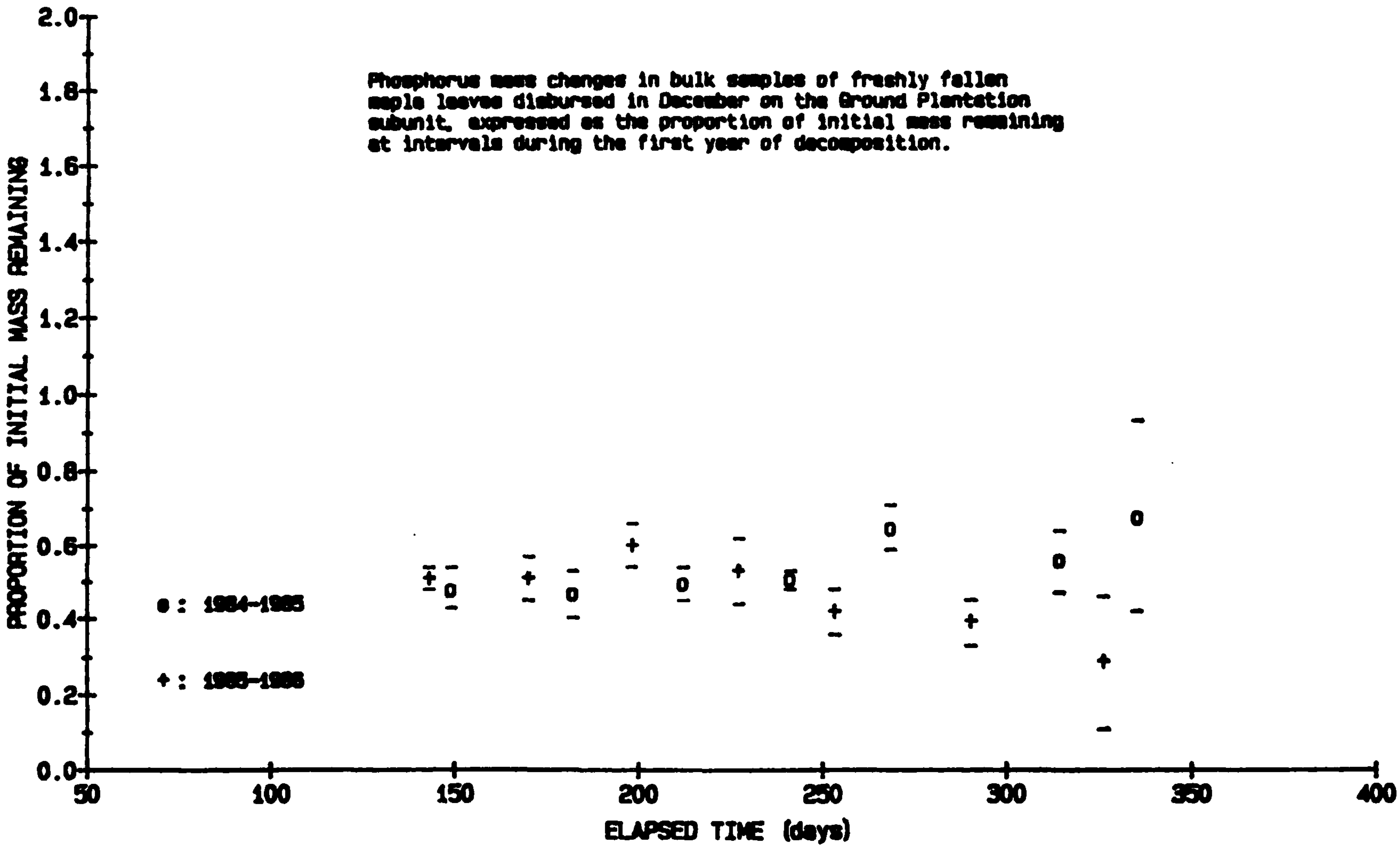


FIGURE 154.

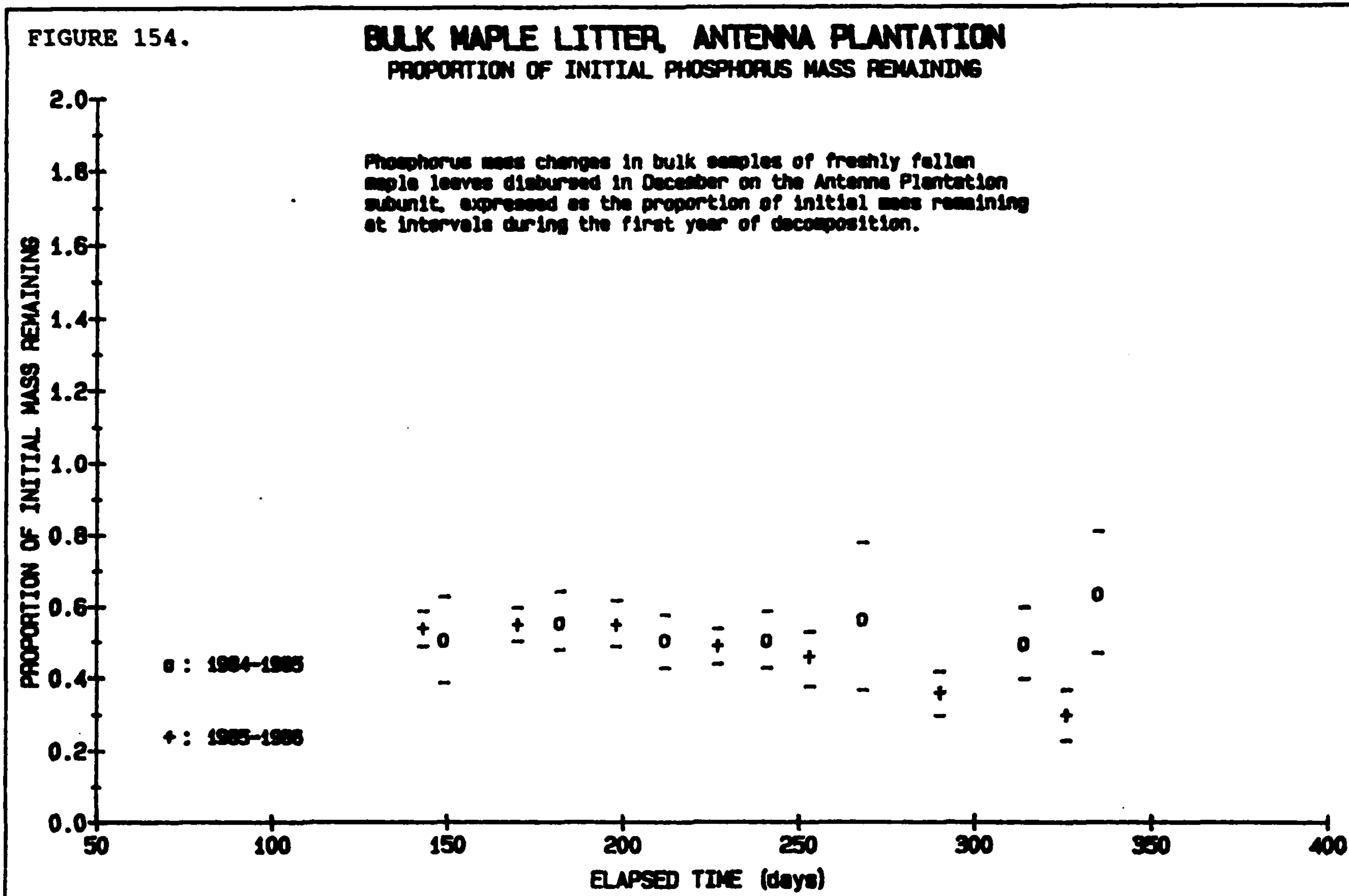

BULK MAPLE LITTER, ANTENNA PLANTATION
PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING
Phosphorus mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Antenna Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
o : 1984-1985
+ : 1985-1986
PROPORTION OF INITIAL MASS REMAINING
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 155.

BULK MAPLE LITTER, CONTROL PLANTATION

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING

Phosphorus mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Control Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

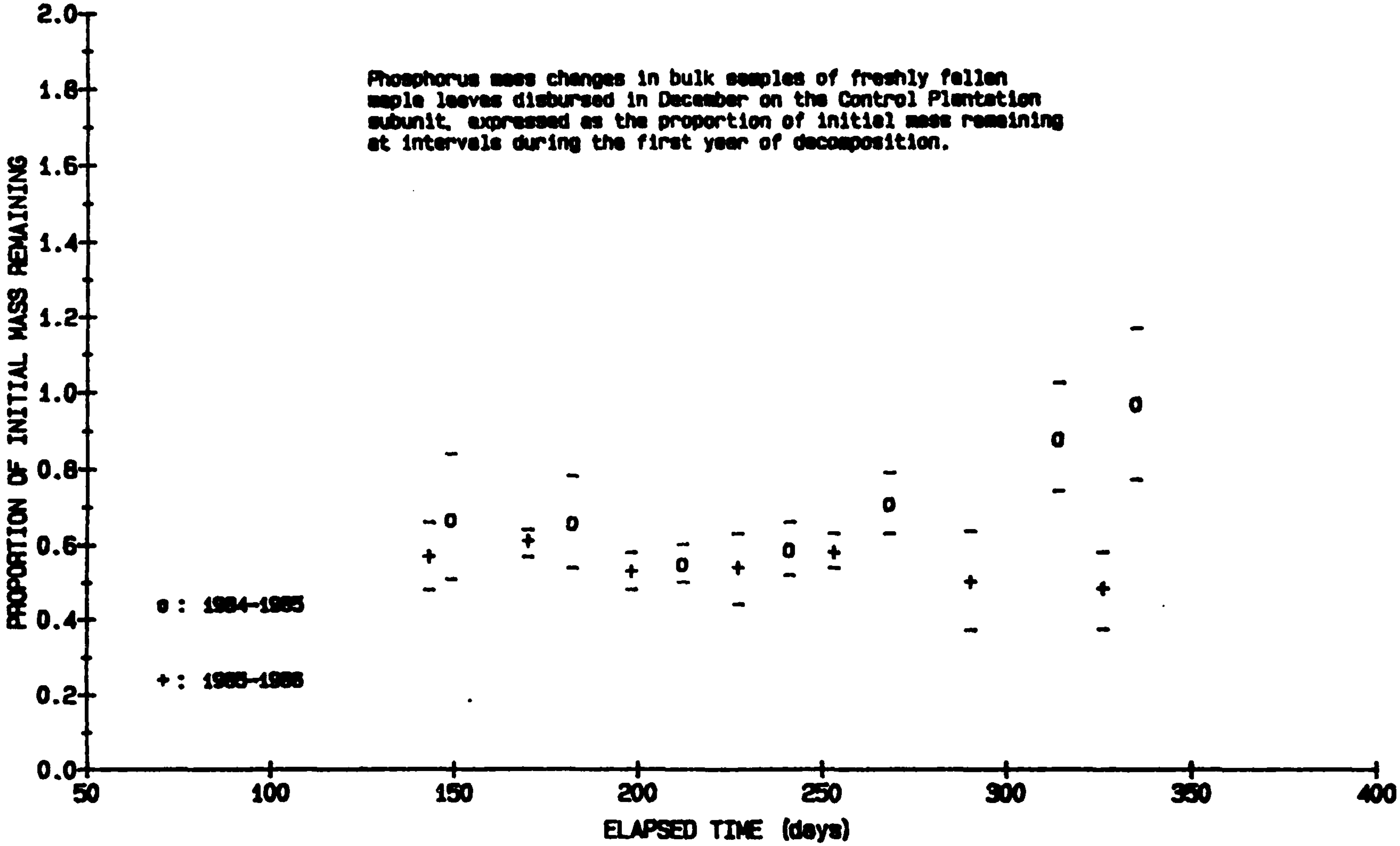
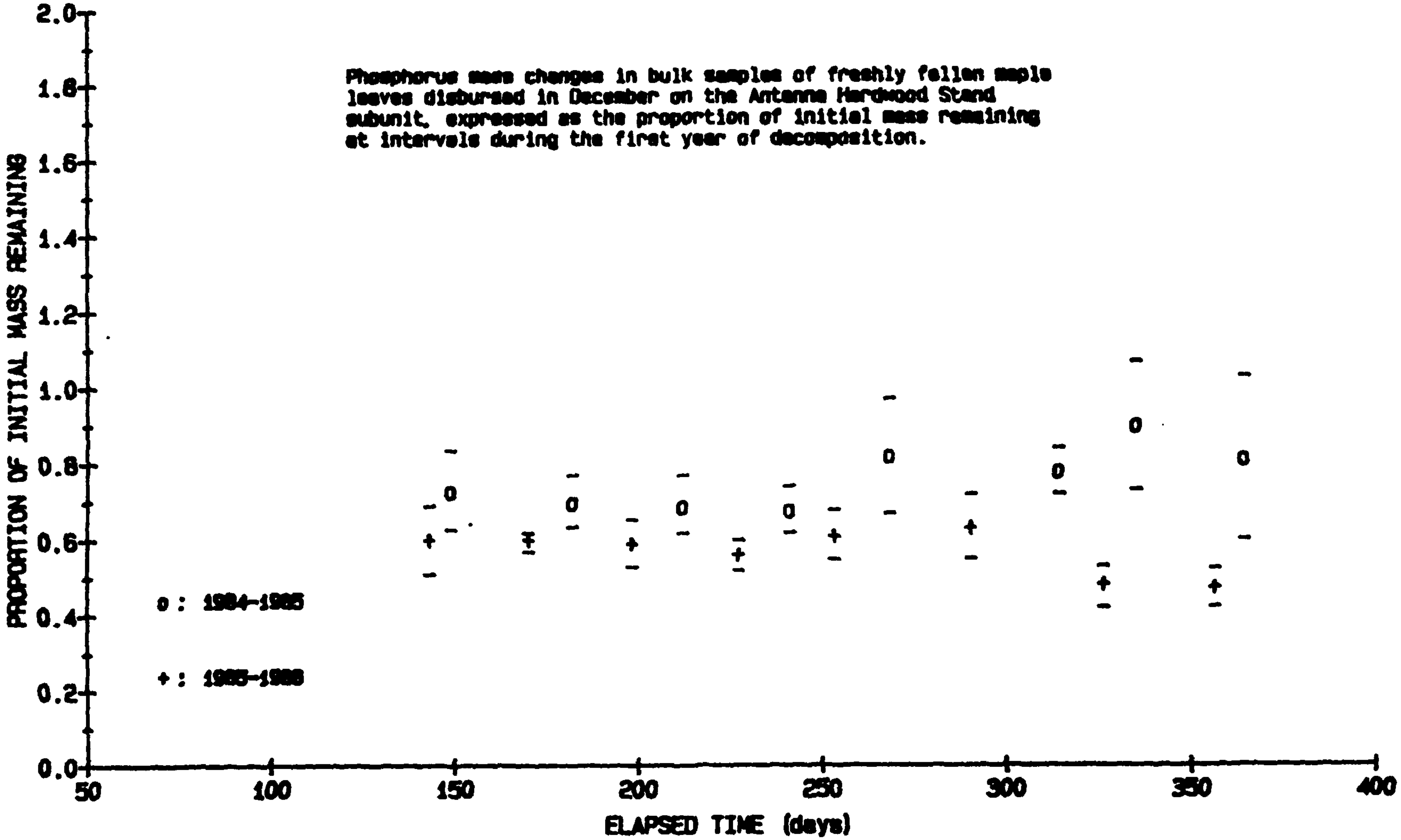


FIGURE 156.

BULK MAPLE LITTER, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING

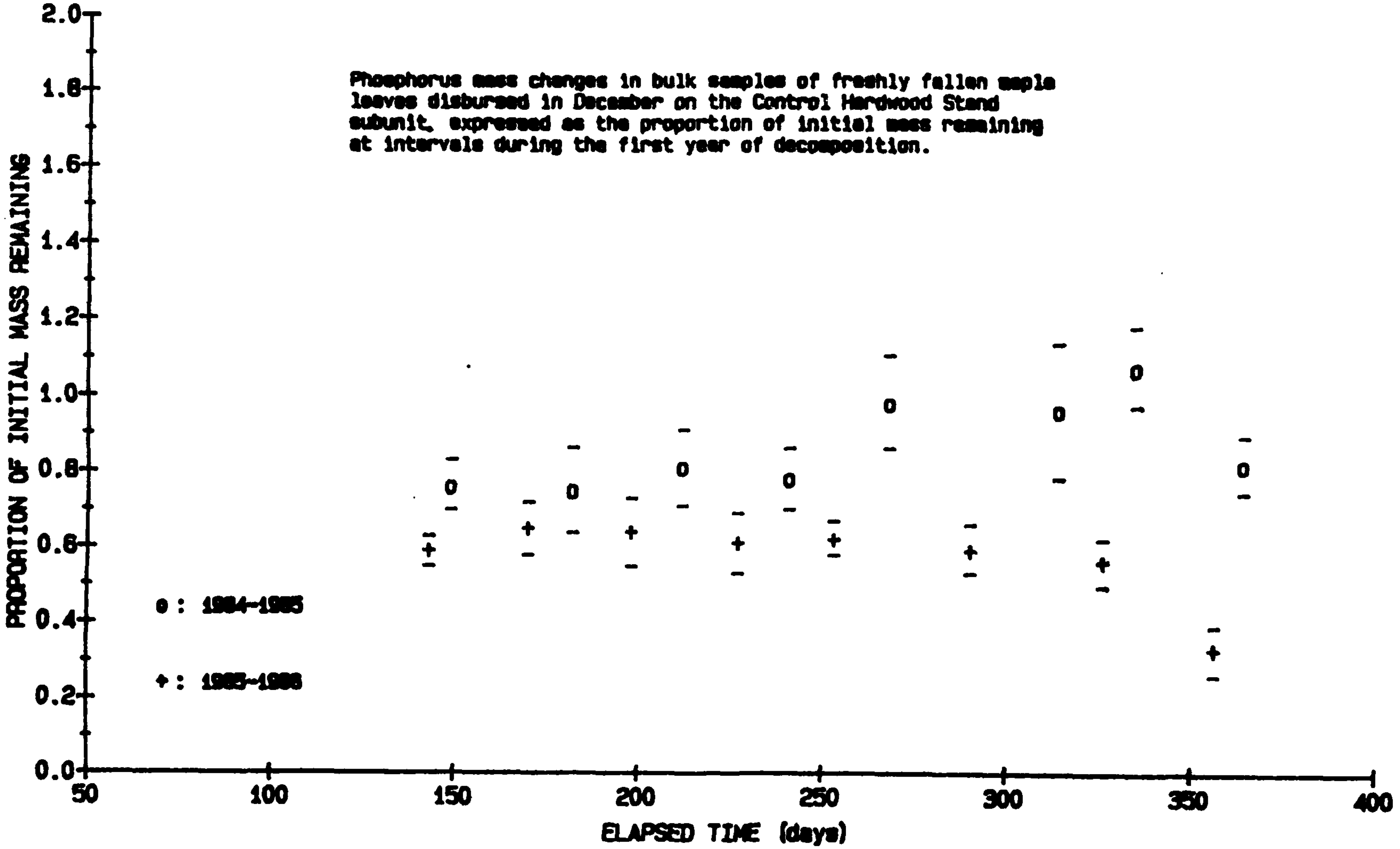


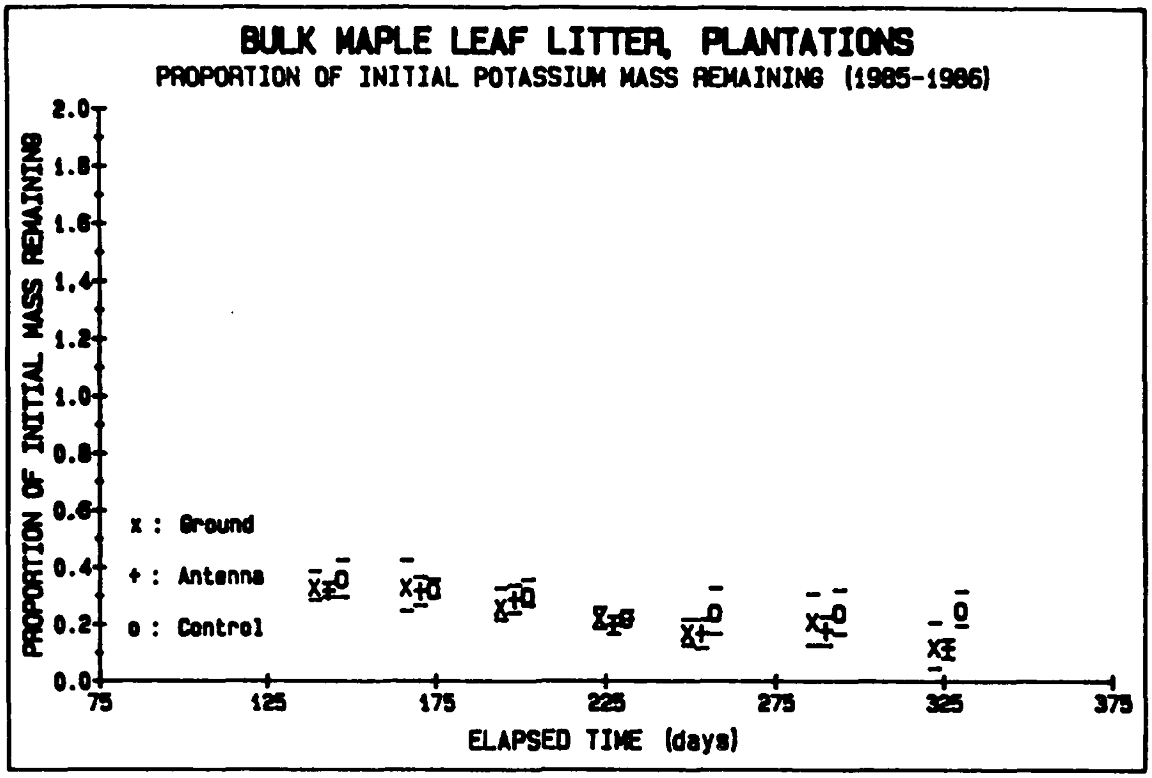
Phosphorus mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Antenna Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

FIGURE 157.

BULK MAPLE LITTER, CONTROL HARDWOOD STAND

PROPORTION OF INITIAL PHOSPHORUS MASS REMAINING




BULK MAPLE LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
x : Ground
+ : Antenna
o : Control
ELAPSED TIME (days)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
75
125
175
225
275
325
375

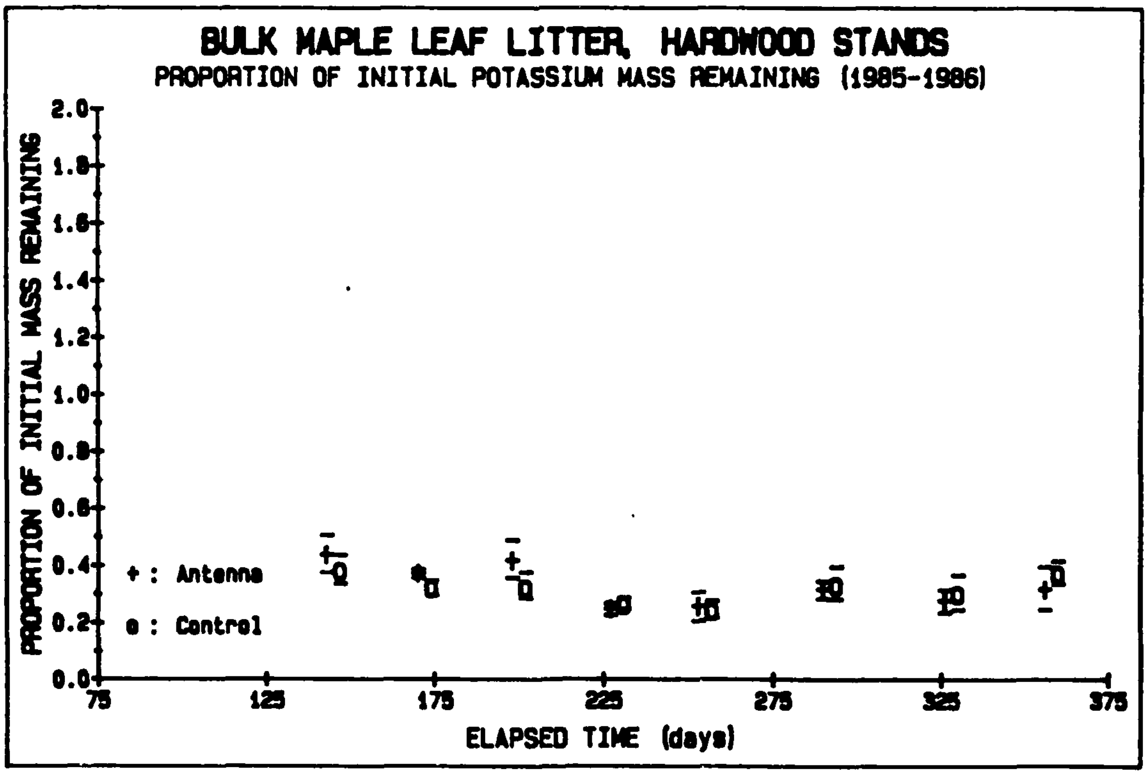
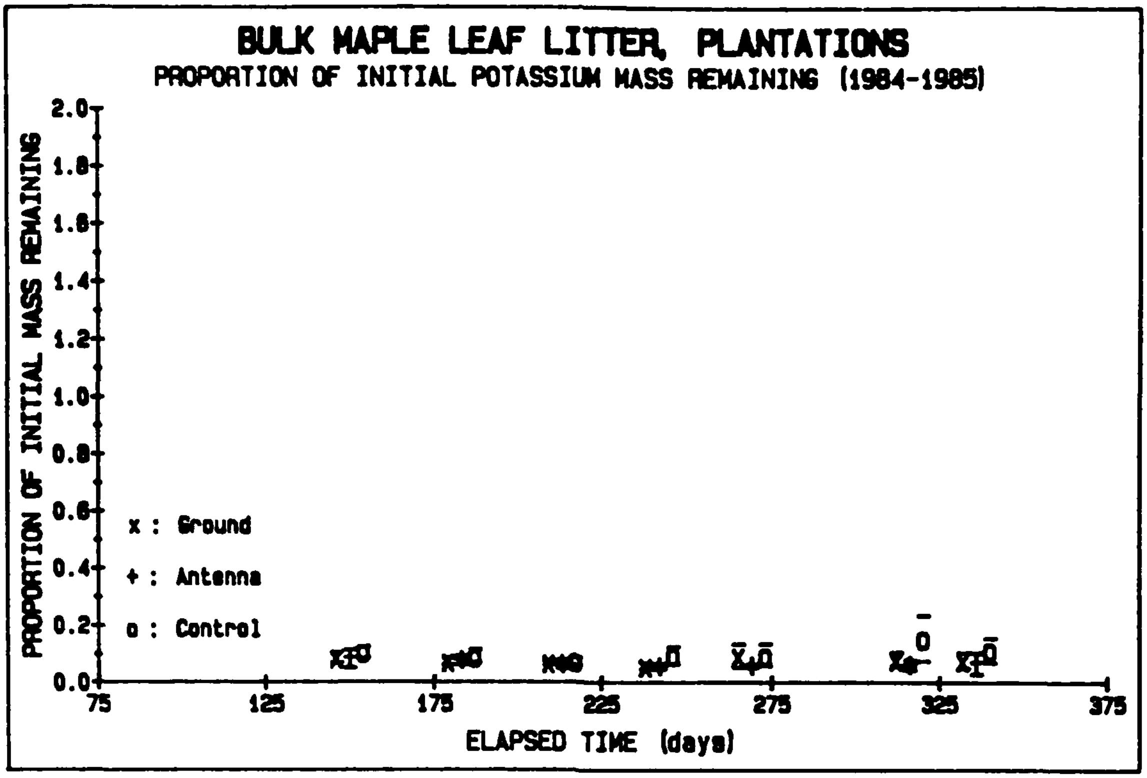

BULK MAPLE LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
+ : Antenna
o : Control
ELAPSED TIME (days)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
75
125
175
225
275
325
375

FIGURE 158.


BULK MAPLE LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

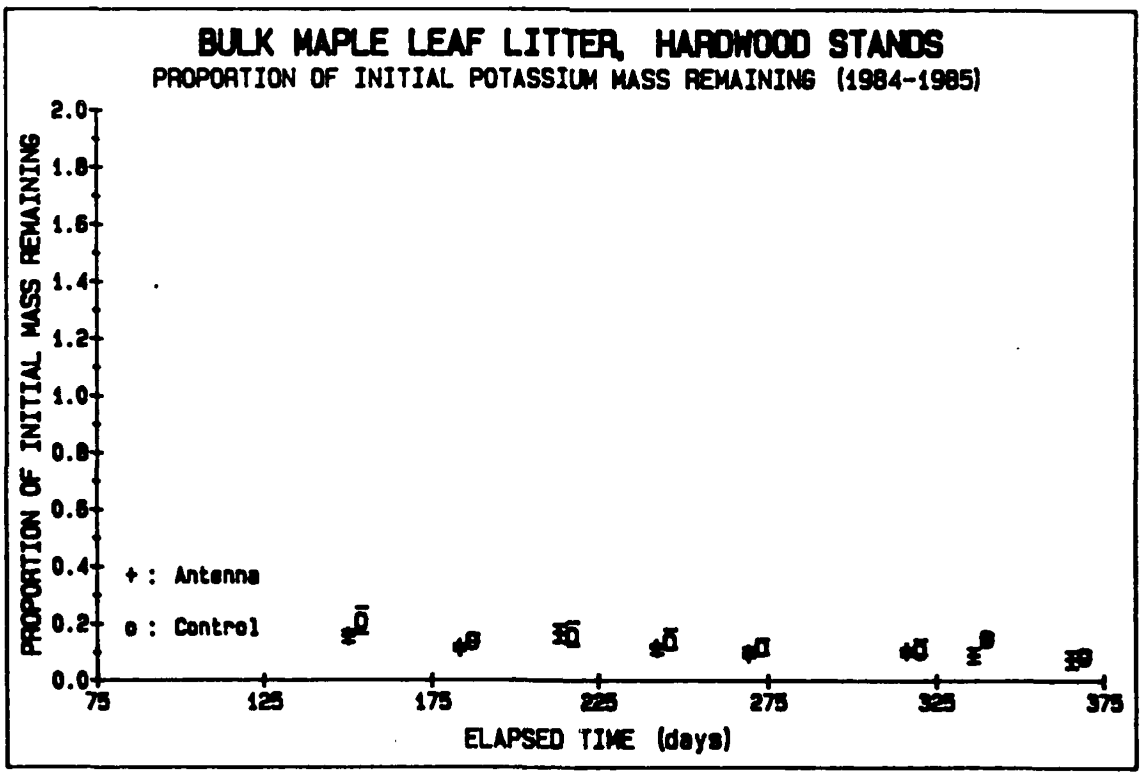

BULK MAPLE LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL POTASSIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

FIGURE 159.

FIGURE 160.

BULK MAPLE LITTER, GROUND PLANTATION

PROPORTION OF INITIAL POTASSIUM MASS REMAINING

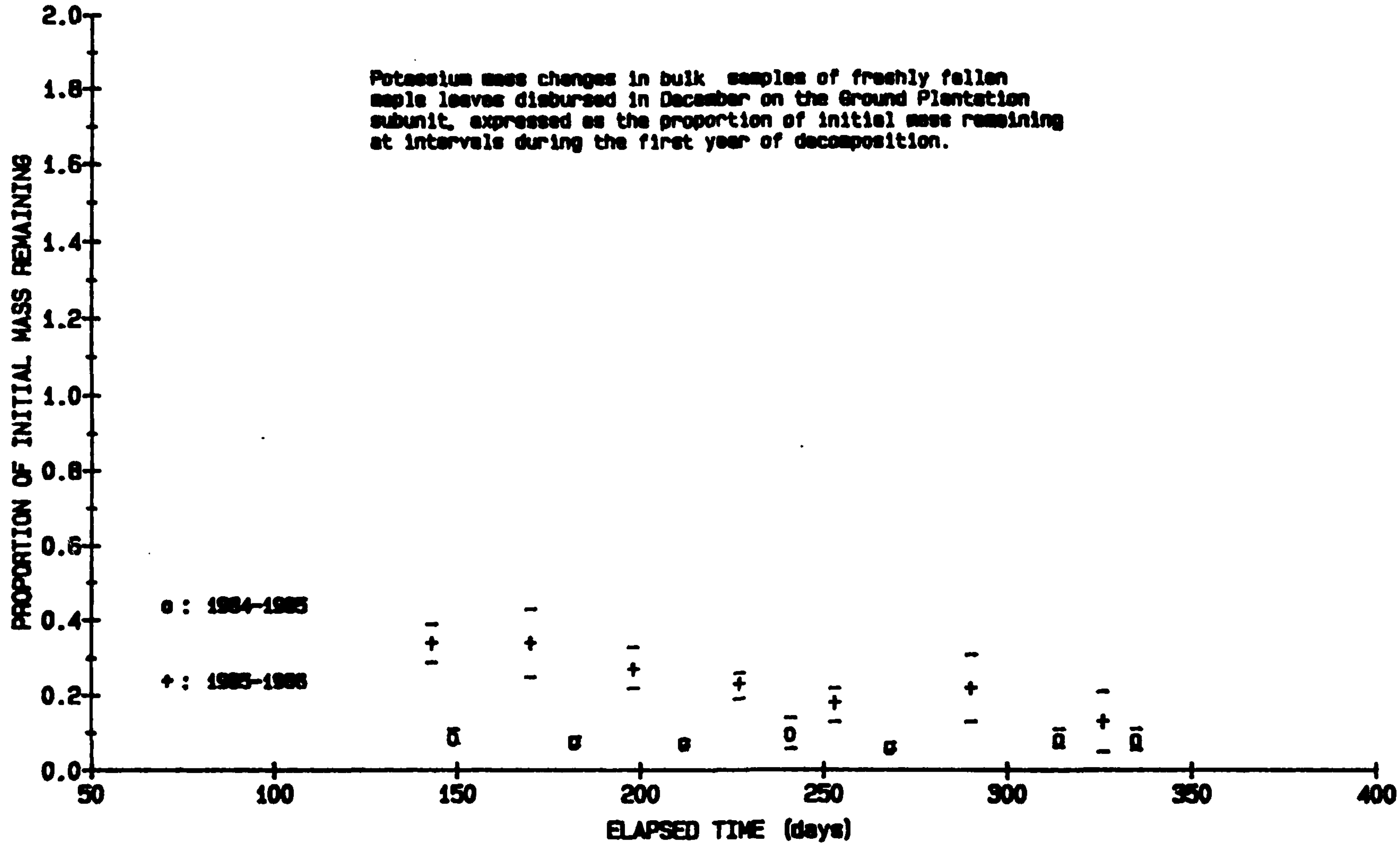


FIGURE 161.

BULK MAPLE LITTER, ANTENNA PLANTATION
PROPORTION OF INITIAL POTASSIUM MASS REMAINING

Potassium mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Antenna Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

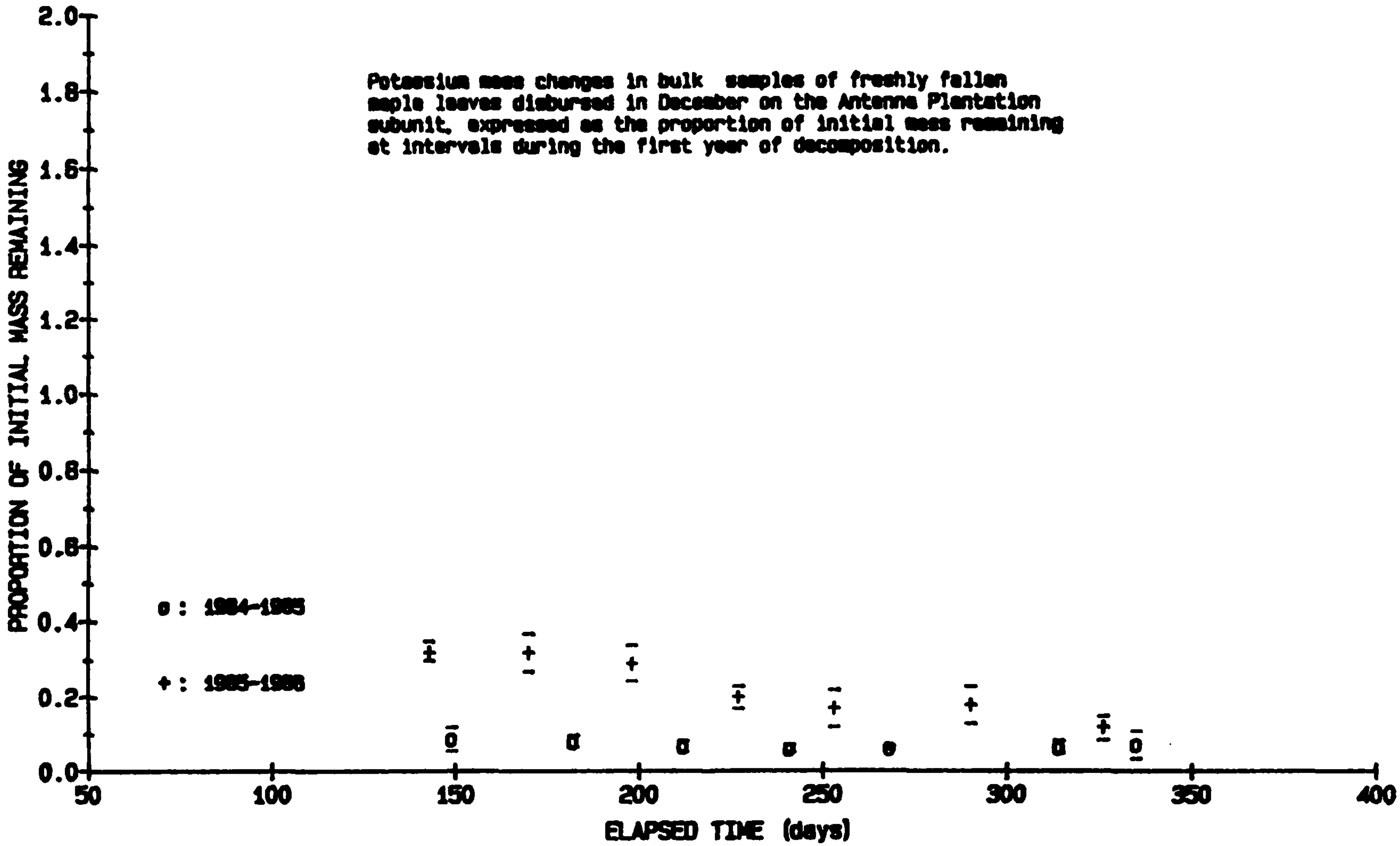


FIGURE 162.

BULK MAPLE LITTER, CONTROL PLANTATION
PROPORTION OF INITIAL POTASSIUM MASS REMAINING

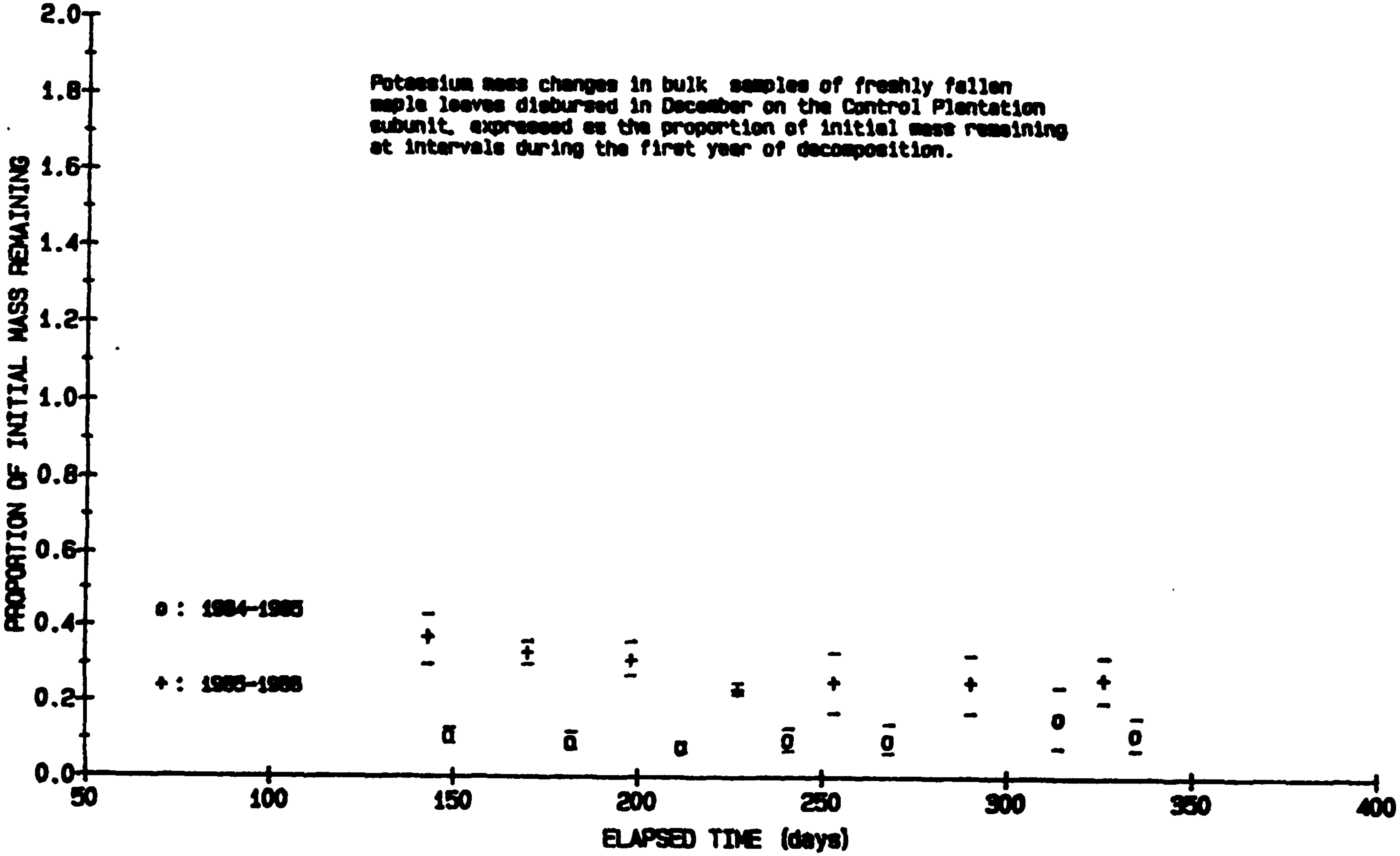


FIGURE 163.

BULK MAPLE LITTER, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL POTASSIUM MASS REMAINING

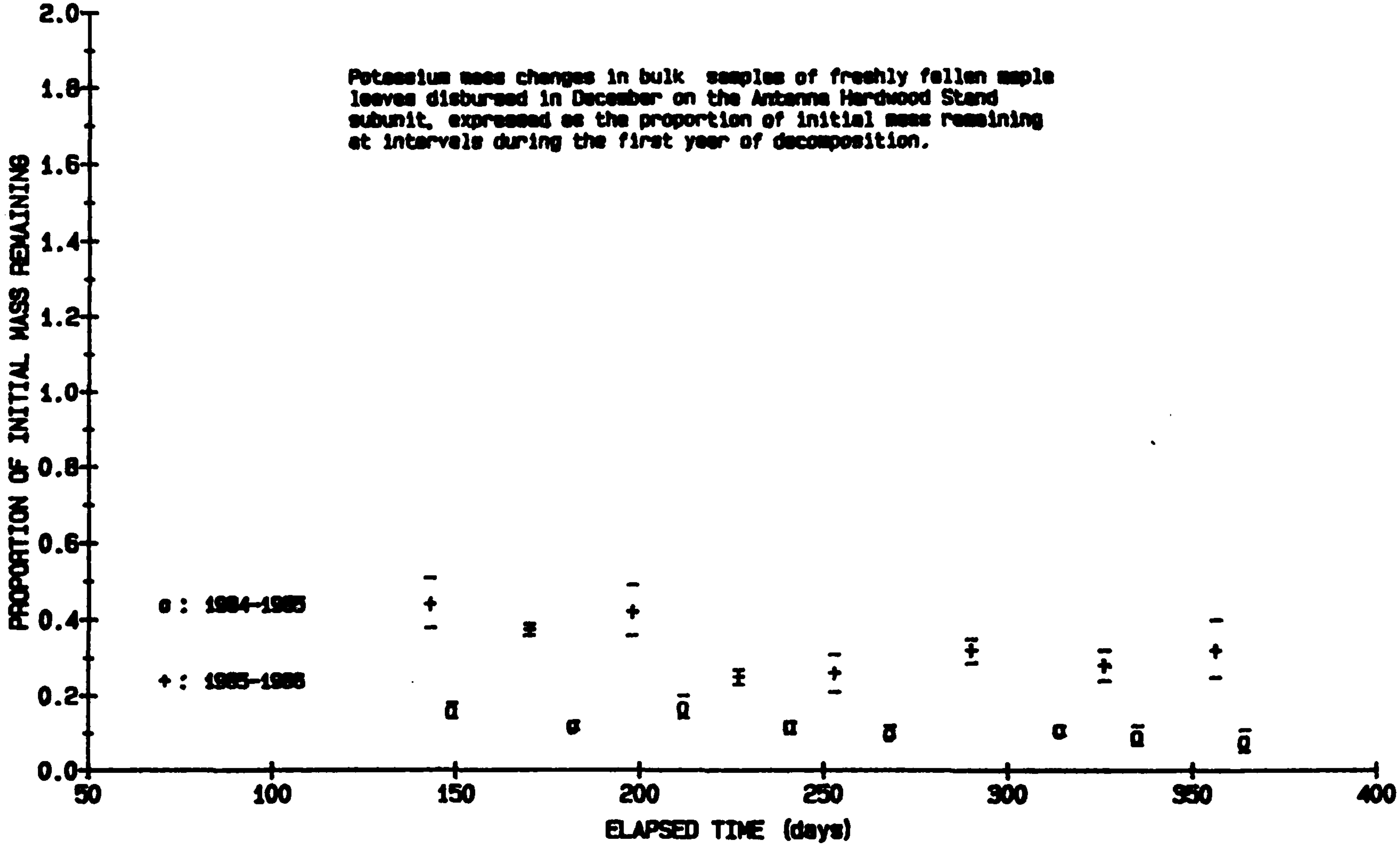
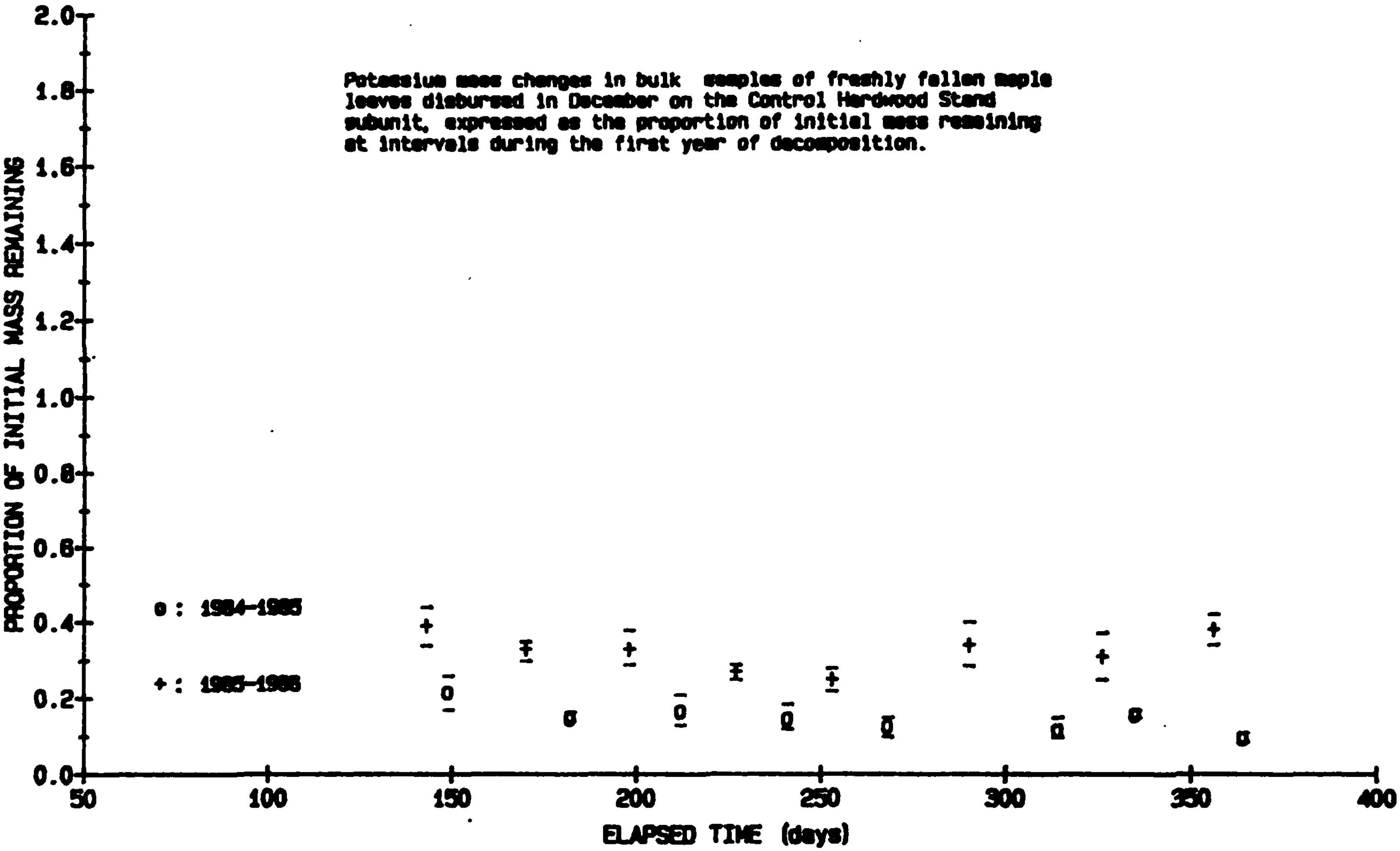


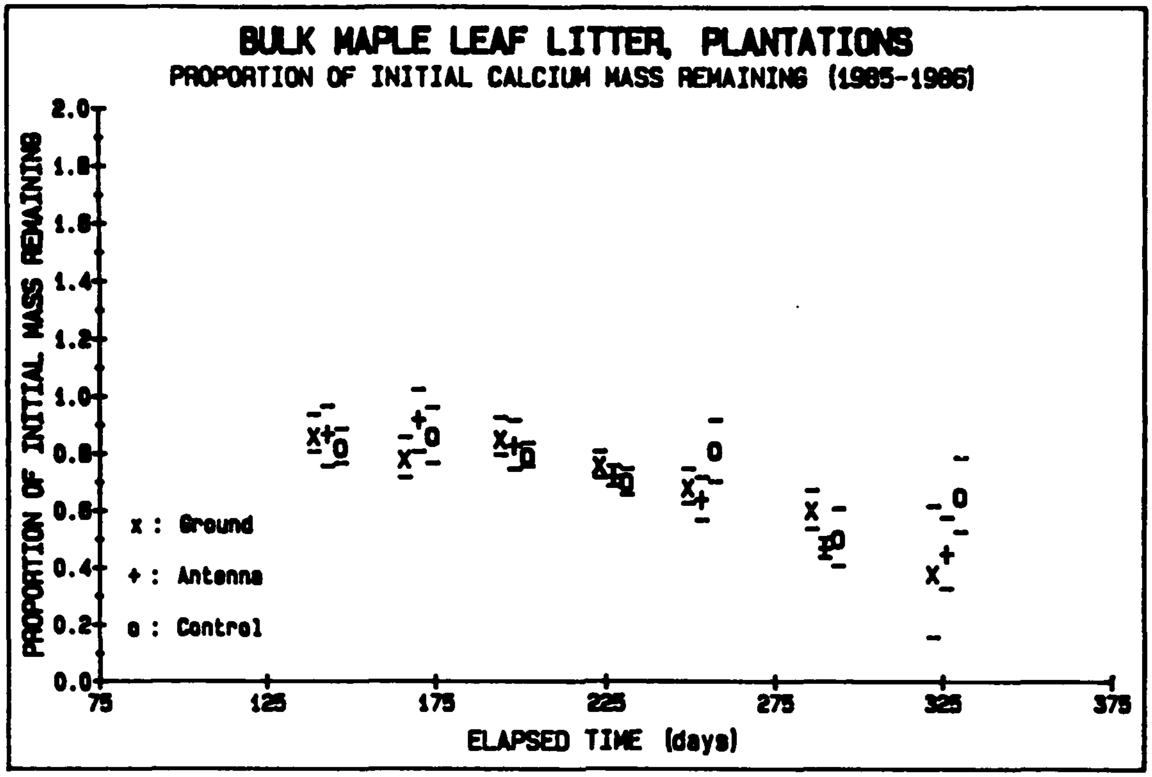
FIGURE 164.

BULK MAPLE LITTER, CONTROL HARDWOOD STAND

PROPORTION OF INITIAL POTASSIUM MASS REMAINING

Potassium mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Control Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.




BULK MAPLE LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL CALCIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

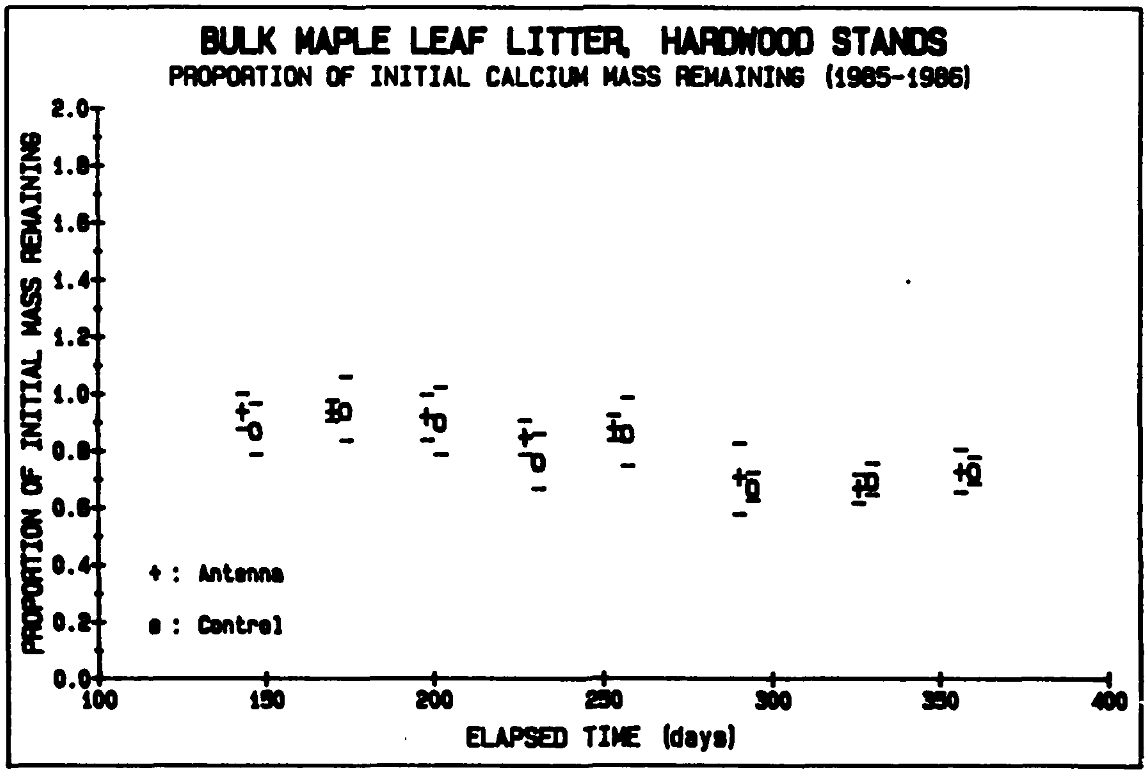
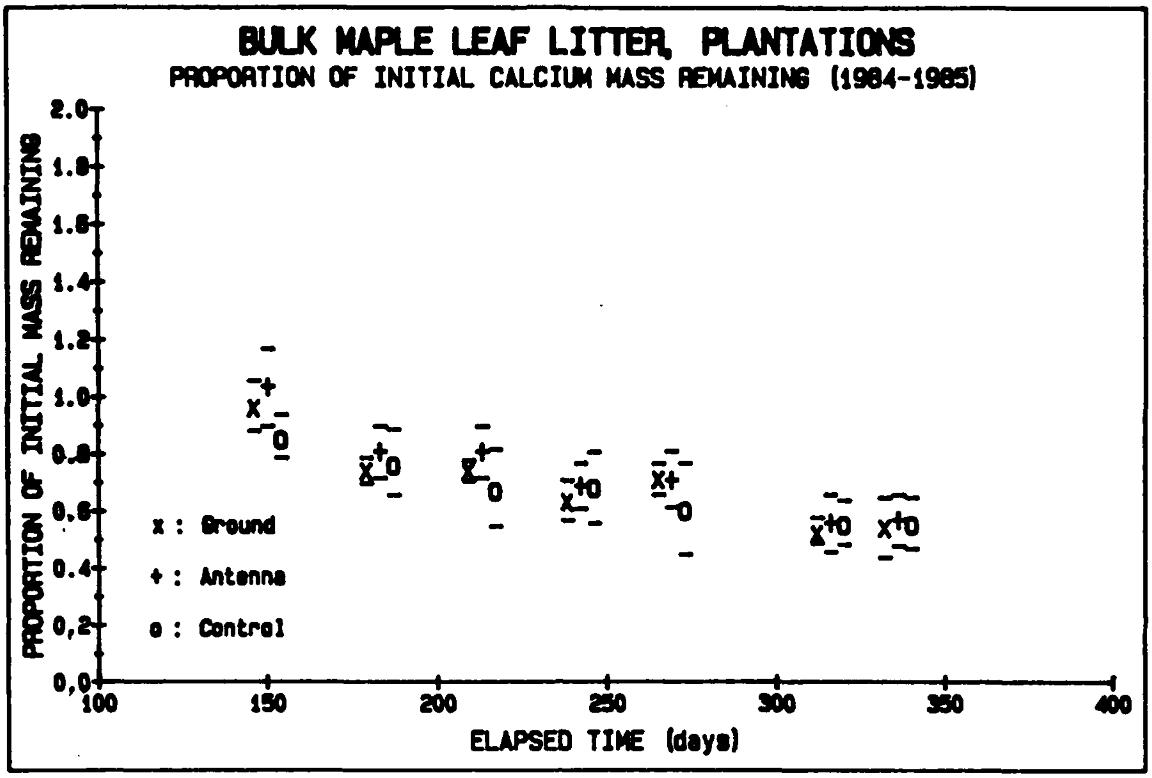

BULK MAPLE LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL CALCIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 165.


BULK MAPLE LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL CALCIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

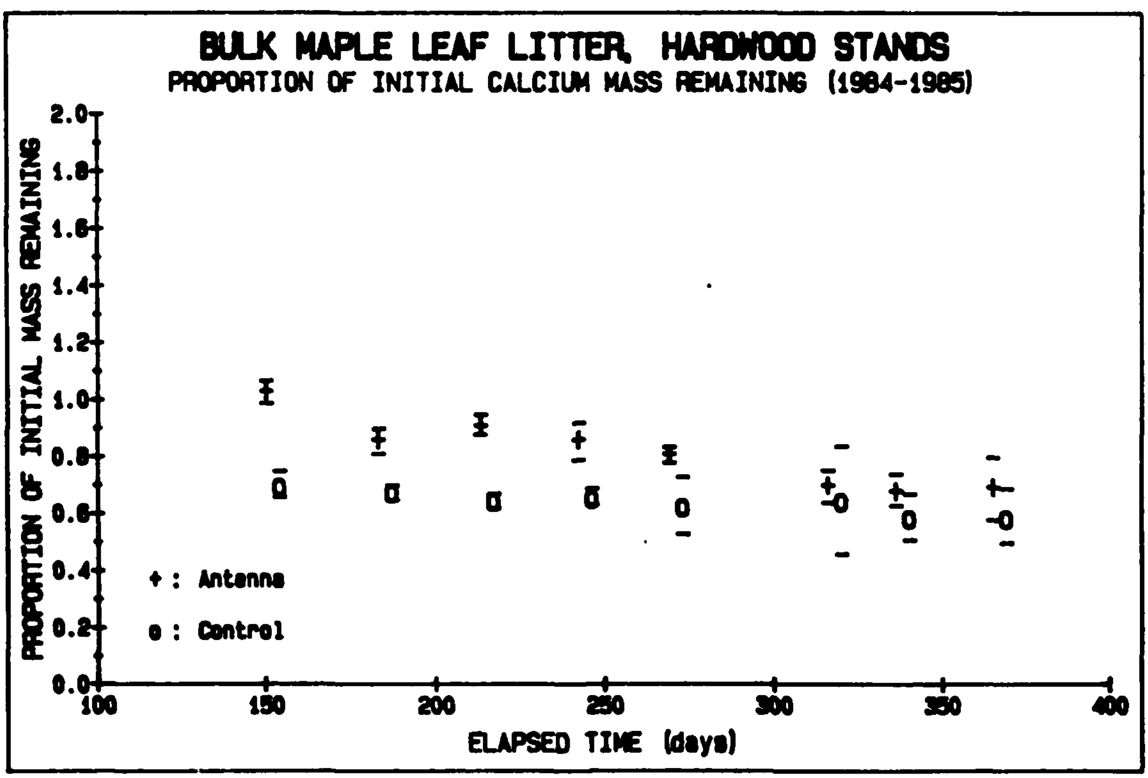
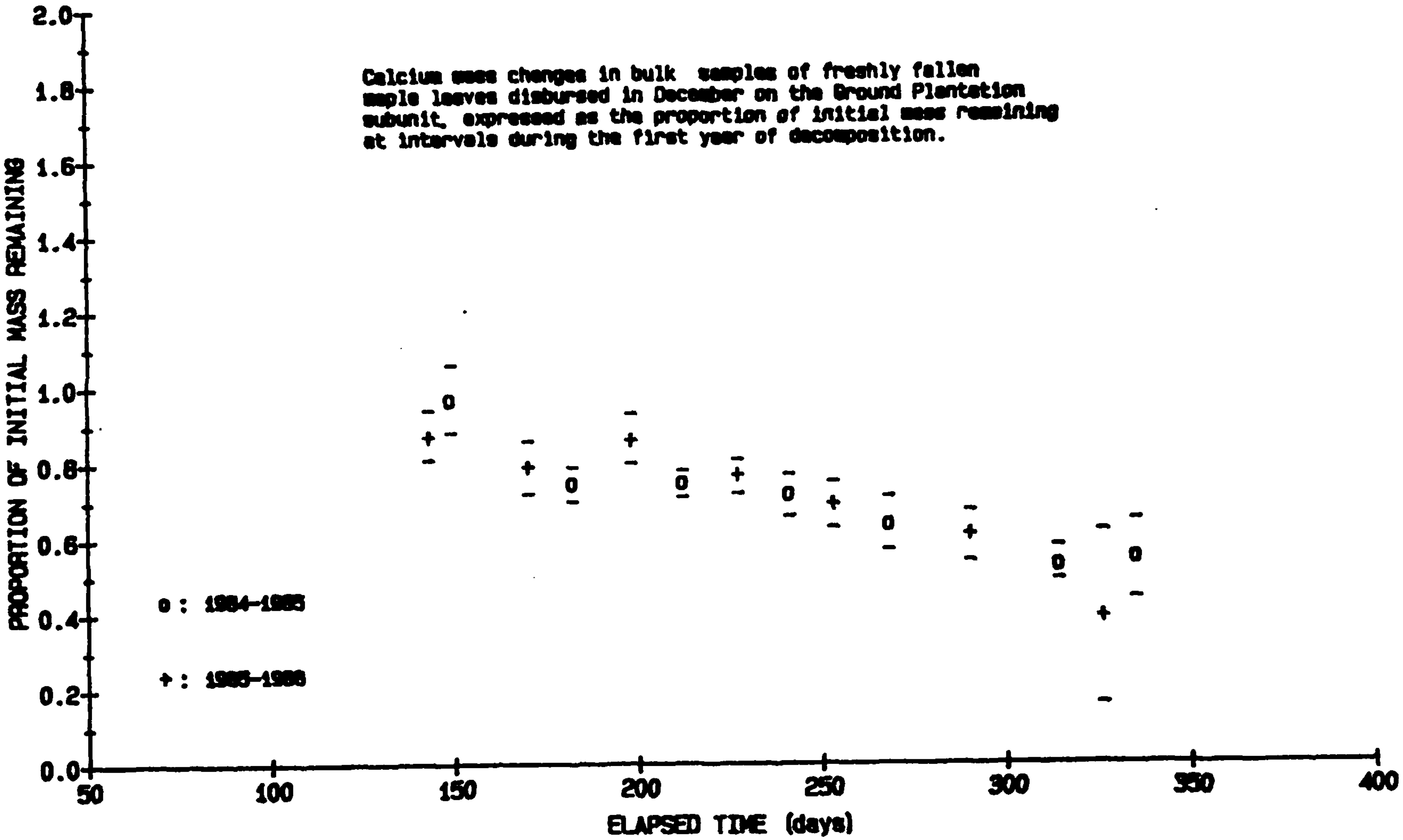

BULK MAPLE LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL CALCIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 166.

FIGURE 167.

BULK MAPLE LITTER, GROUND PLANTATION
PROPORTION OF INITIAL CALCIUM MASS REMAINING



Calcium mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Ground Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

FIGURE 168.

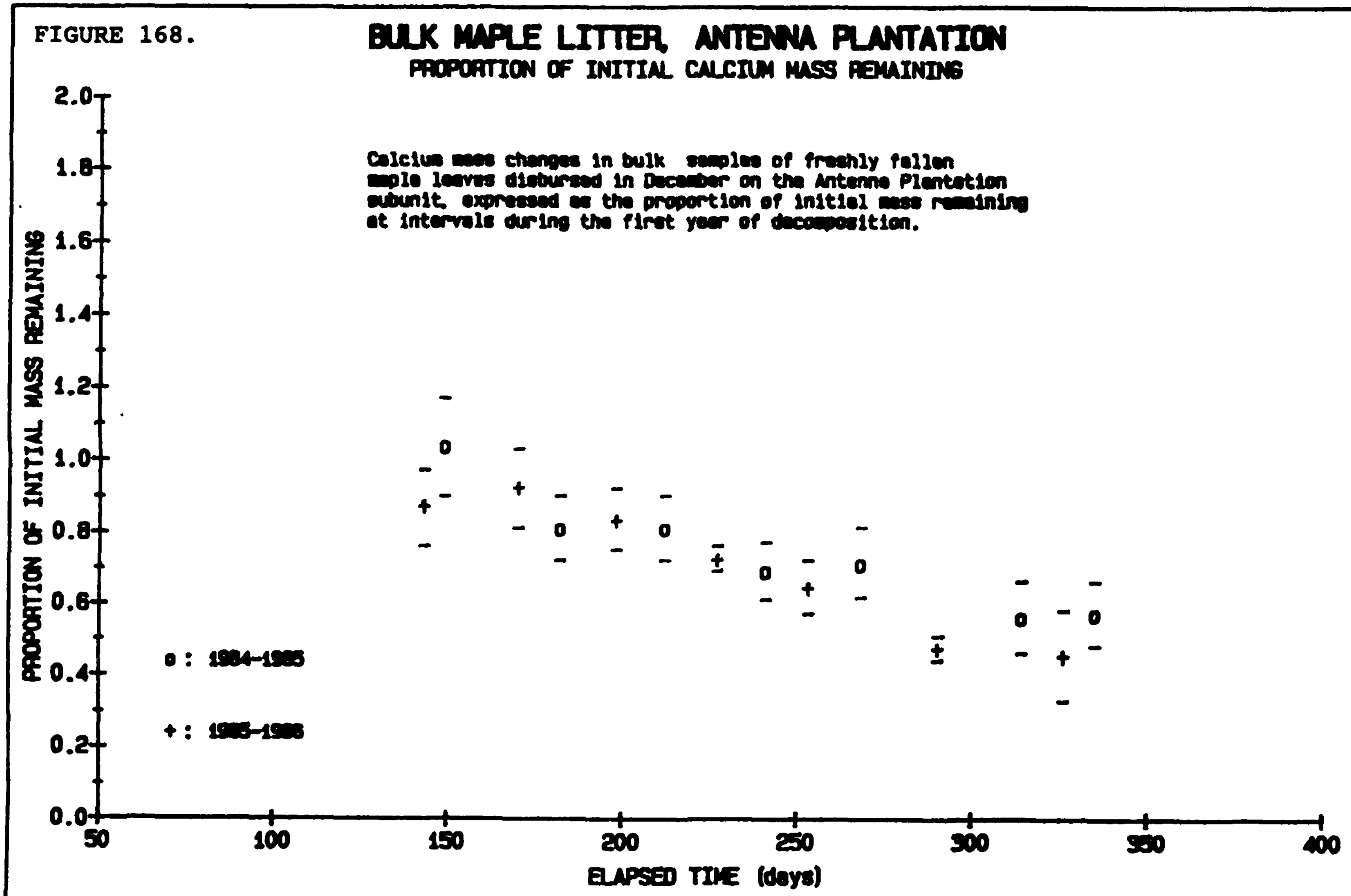

BULK MAPLE LITTER, ANTENNA PLANTATION
PROPORTION OF INITIAL CALCIUM MASS REMAINING
Calcium mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Antenna Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
o : 1984-1985
+ : 1985-1986
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 169.

BULK MAPLE LITTER, CONTROL PLANTATION

PROPORTION OF INITIAL CALCIUM MASS REMAINING

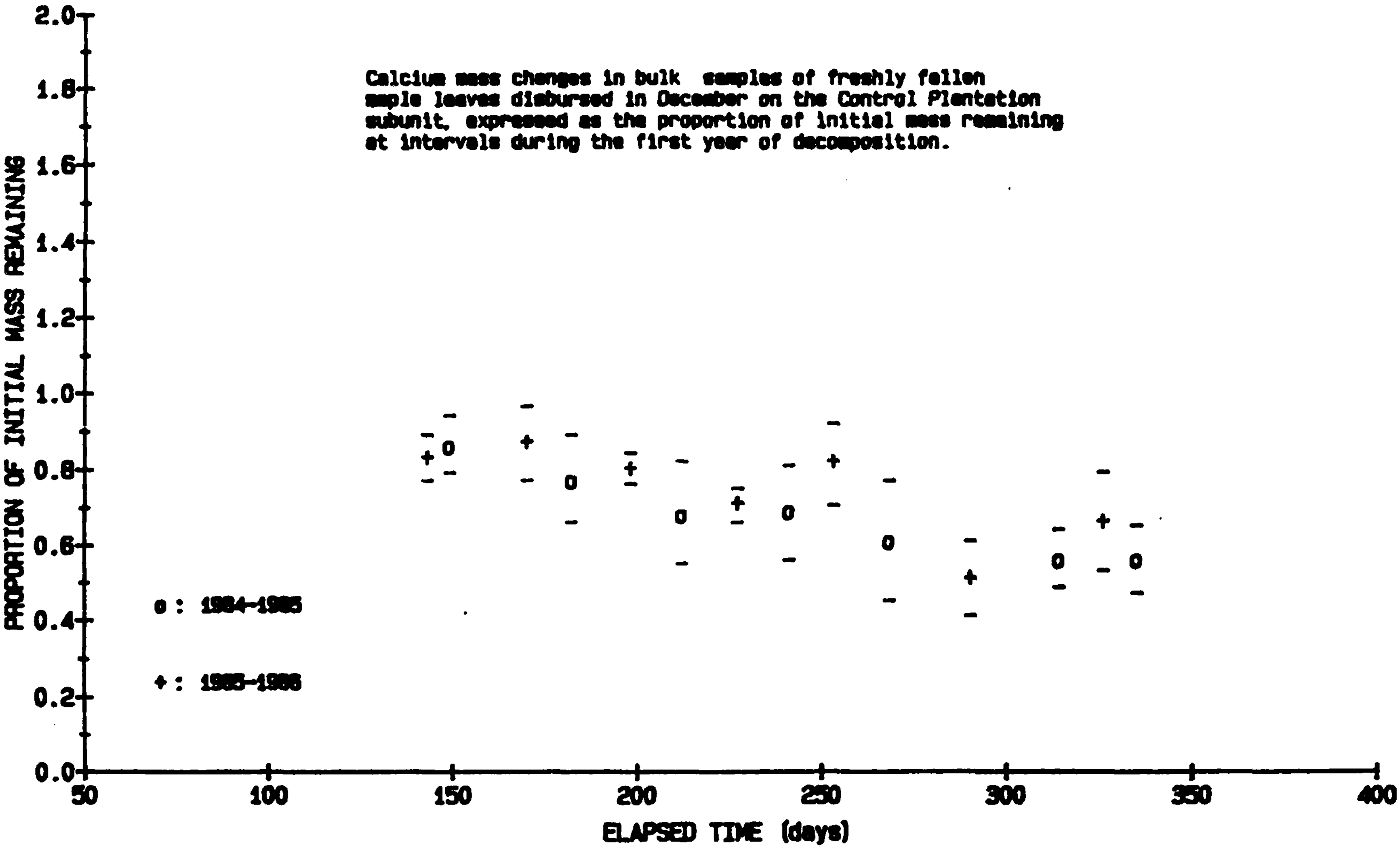


FIGURE 170.

BULK MAPLE LITTER, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL CALCIUM MASS REMAINING

Calcium mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Antenna Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

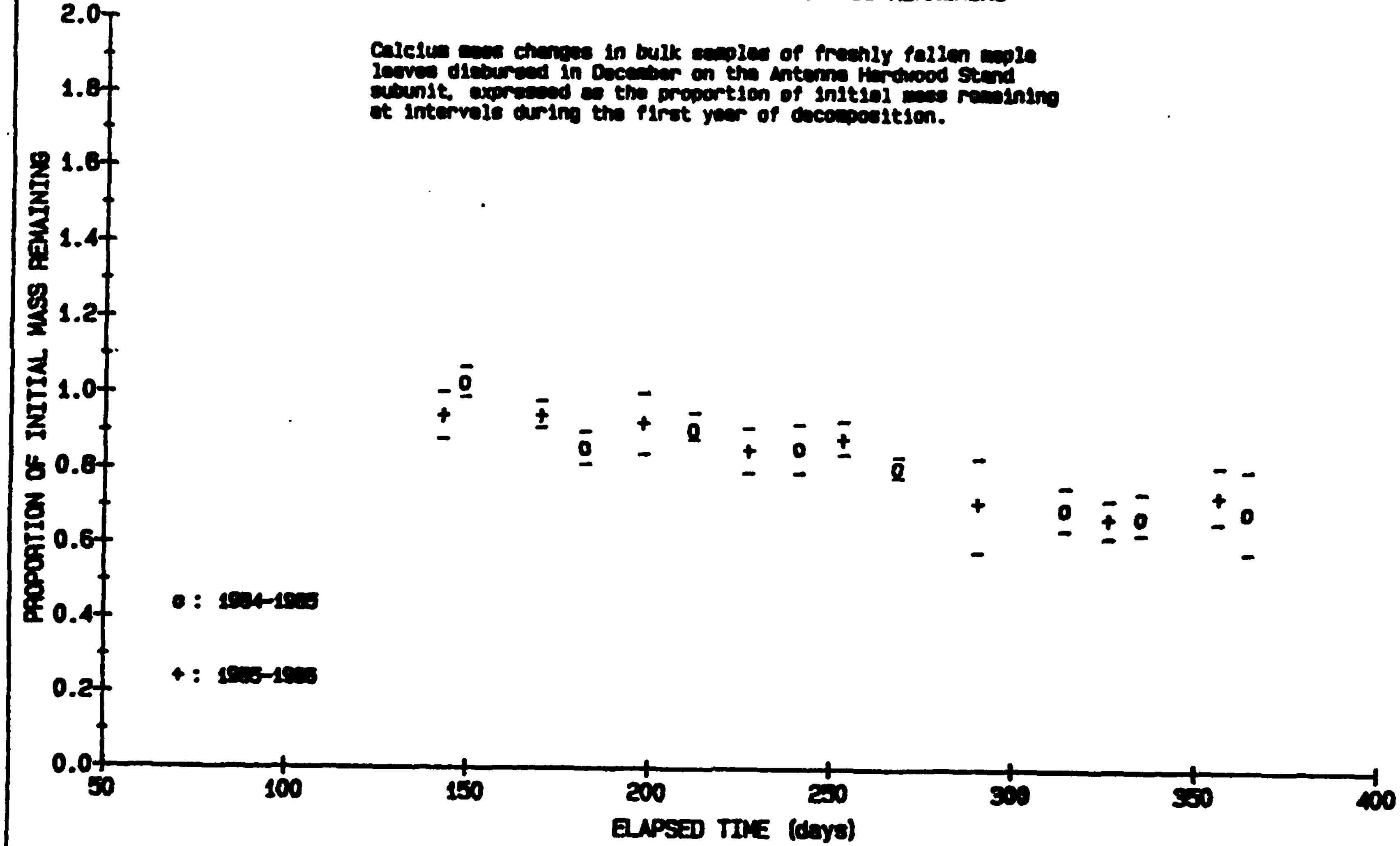
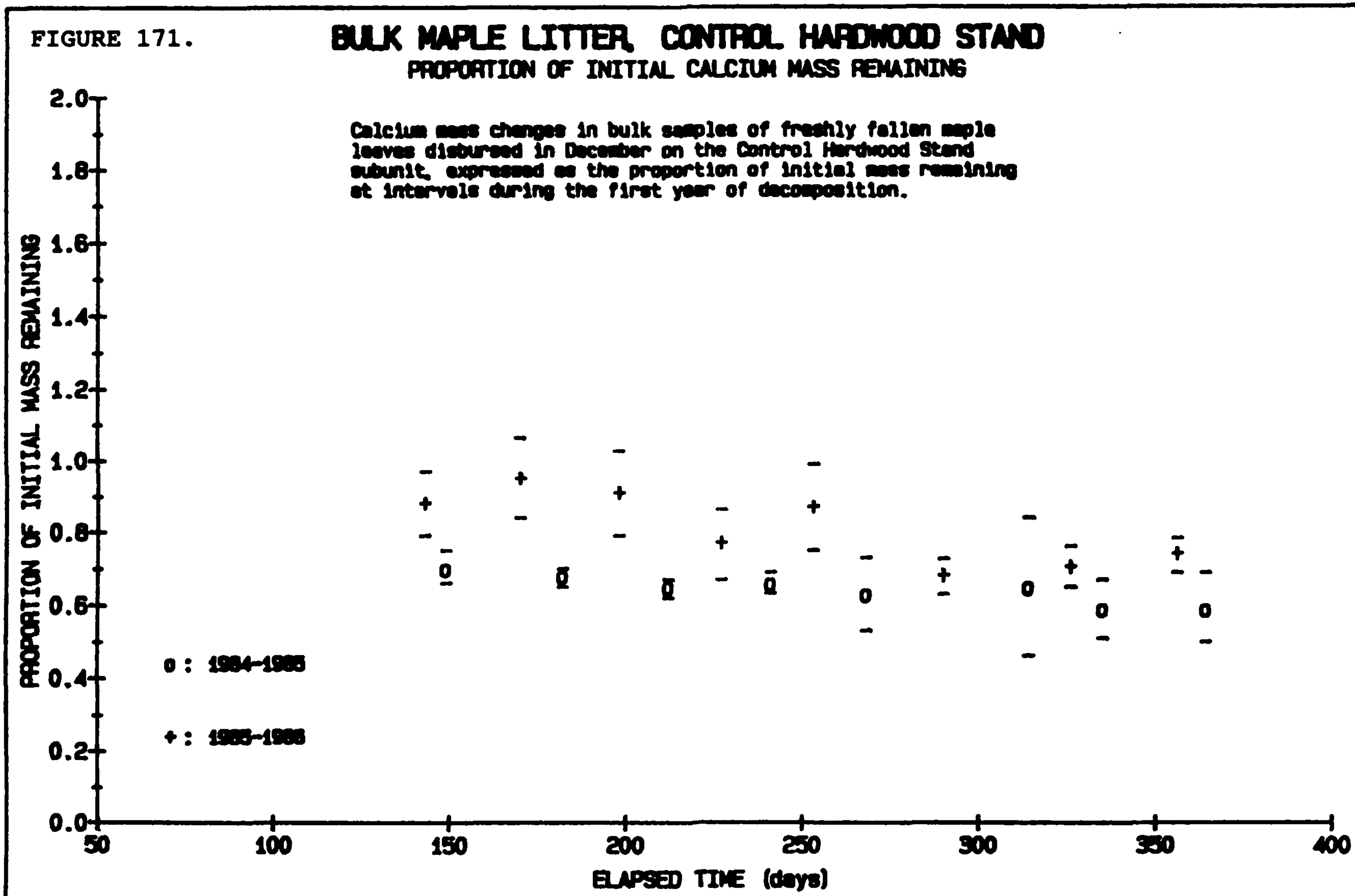
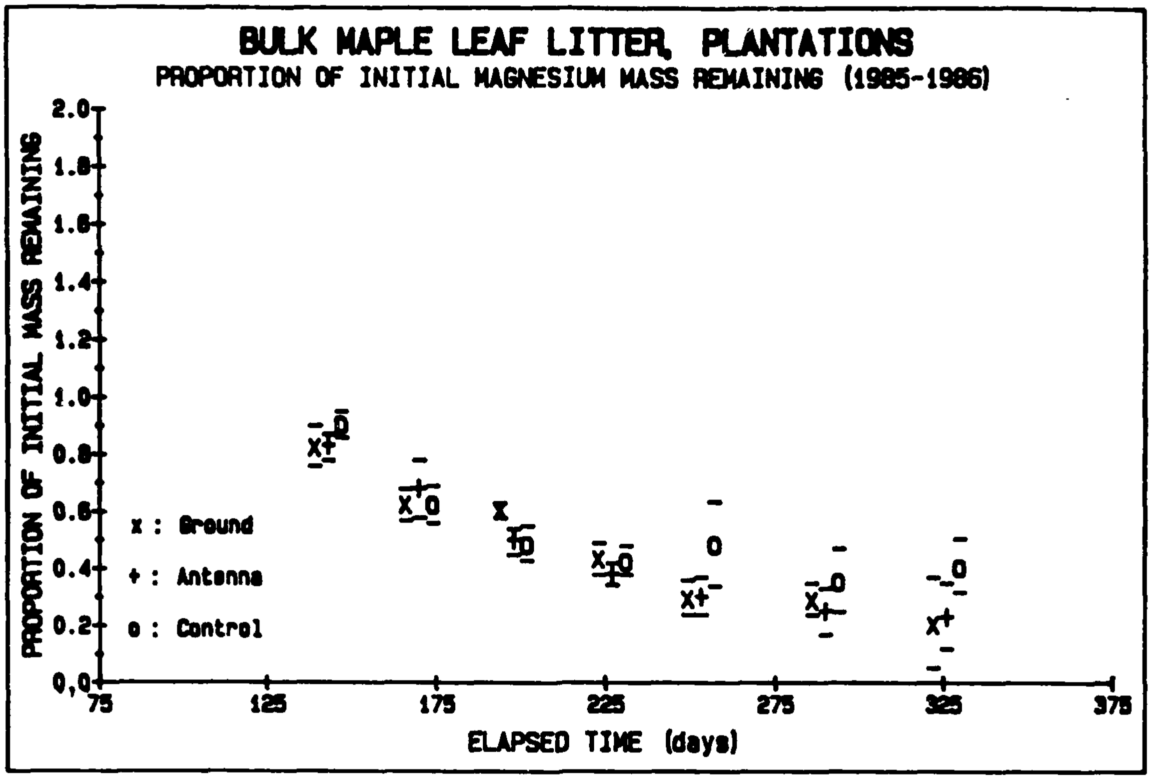


FIGURE 171.


BULK MAPLE LITTER, CONTROL HARDWOOD STAND
PROPORTION OF INITIAL CALCIUM MASS REMAINING
Calcium mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Control Hardwood Stand subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
o : 1984-1985
+ : 1985-1986
50
100
150
200
250
300
350
400
ELAPSED TIME (days)


BULK MAPLE LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
x : Ground
+ : Antenna
o : Control
ELAPSED TIME (days)

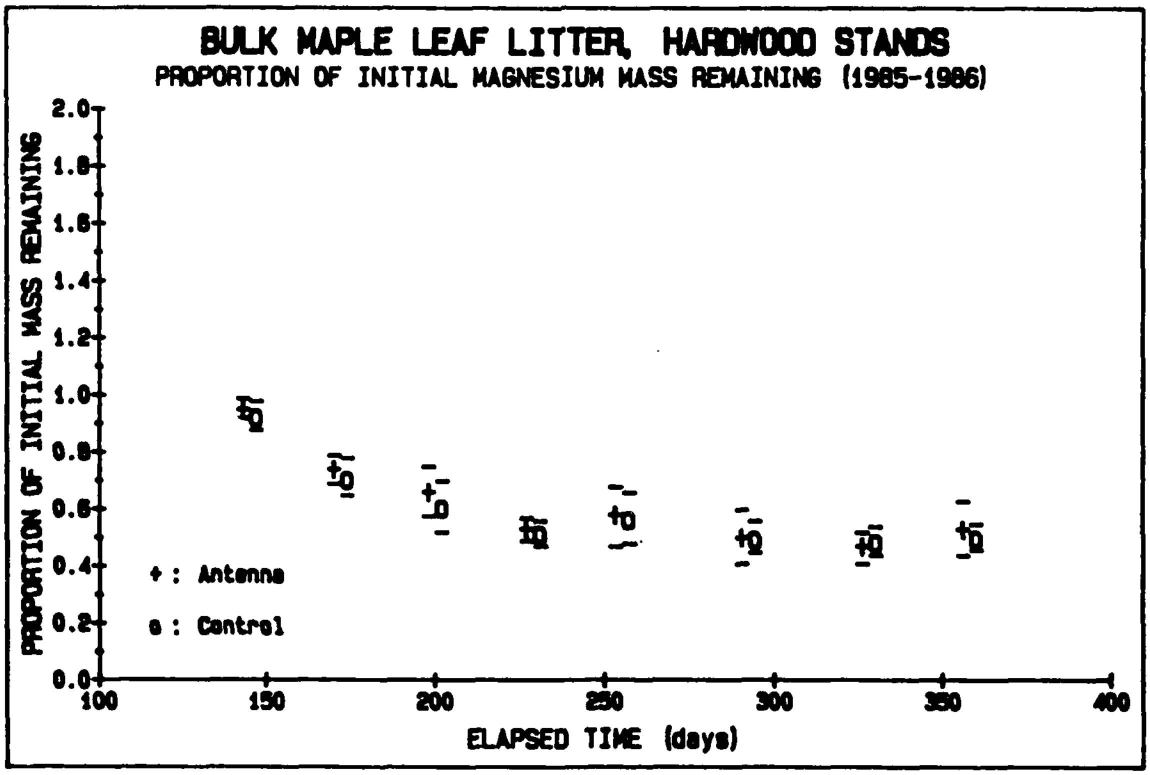
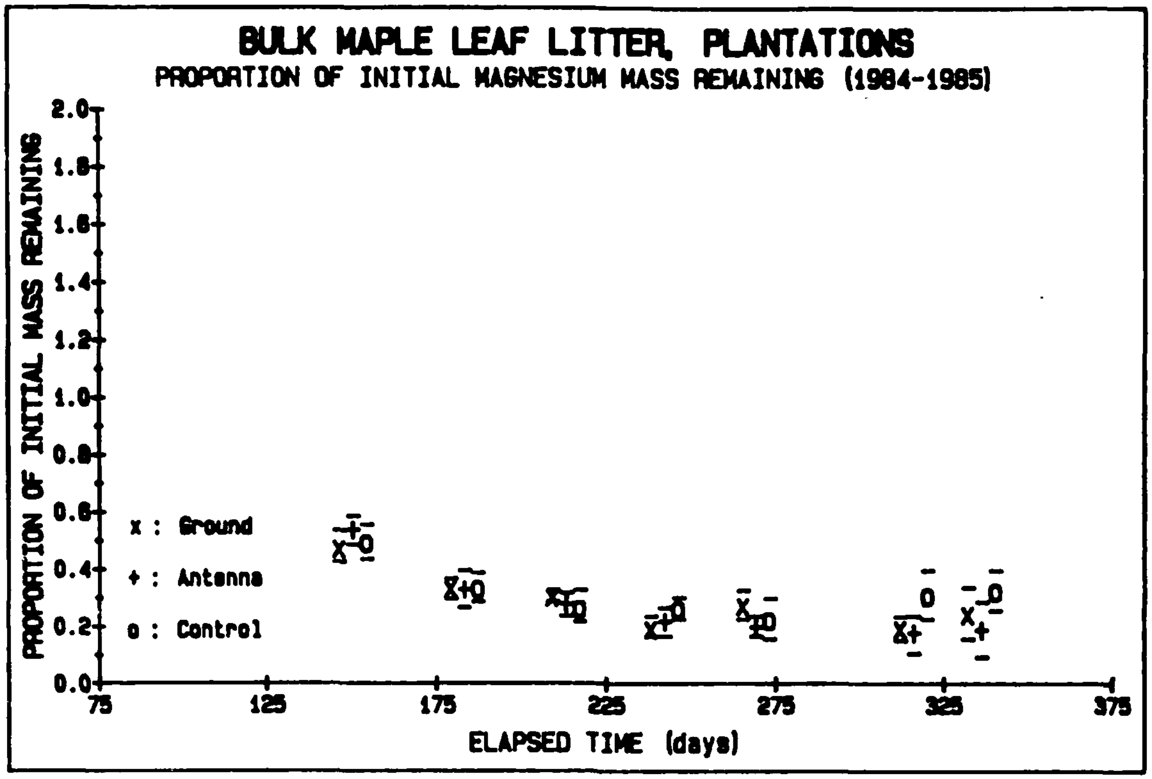

BULK MAPLE LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1985-1986)
PROPORTION OF INITIAL MASS REMAINING
+ : Antenna
o : Control
ELAPSED TIME (days)

FIGURE 172.


BULK MAPLE LEAF LITTER, PLANTATIONS
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
x : Ground
+ : Antenna
o : Control
75
125
175
225
275
325
375
ELAPSED TIME (days)

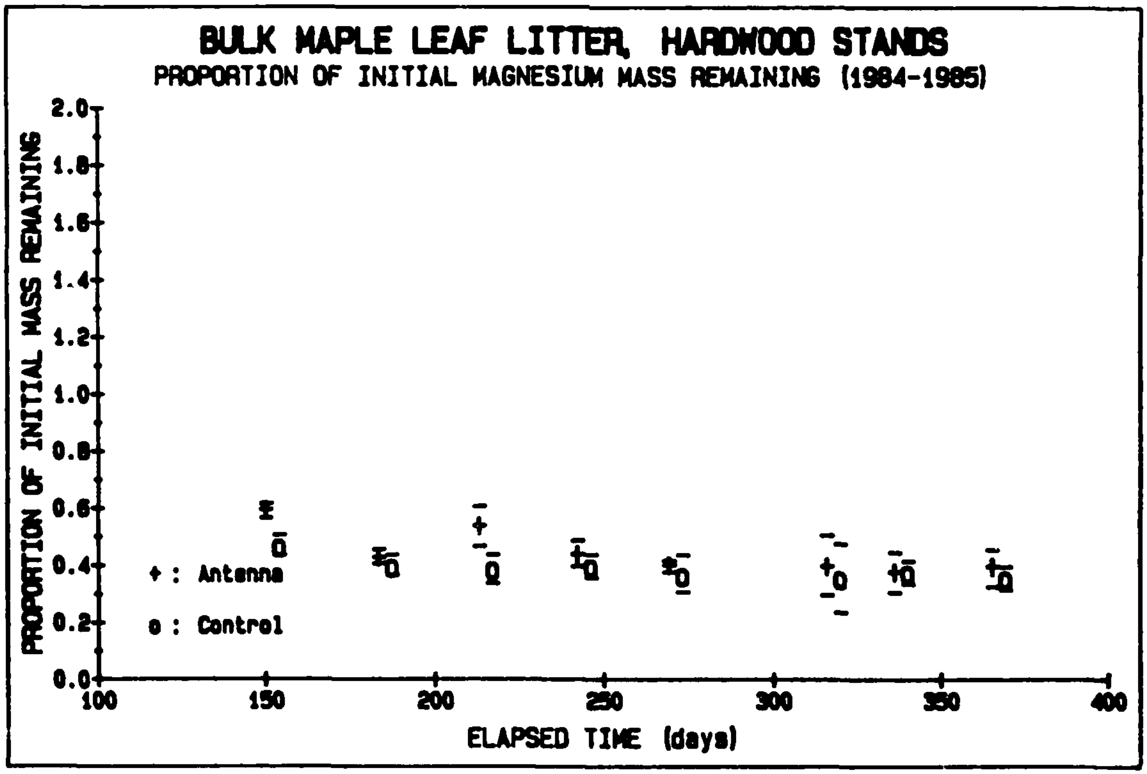

BULK MAPLE LEAF LITTER, HARDWOOD STANDS
PROPORTION OF INITIAL MAGNESIUM MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
+ : Antenna
o : Control
100
150
200
250
300
350
400
ELAPSED TIME (days)

FIGURE 173.

FIGURE 174.

BULK MAPLE LITTER, GROUND PLANTATION

PROPORTION OF INITIAL MAGNESIUM MASS REMAINING

Magnesium mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Ground Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

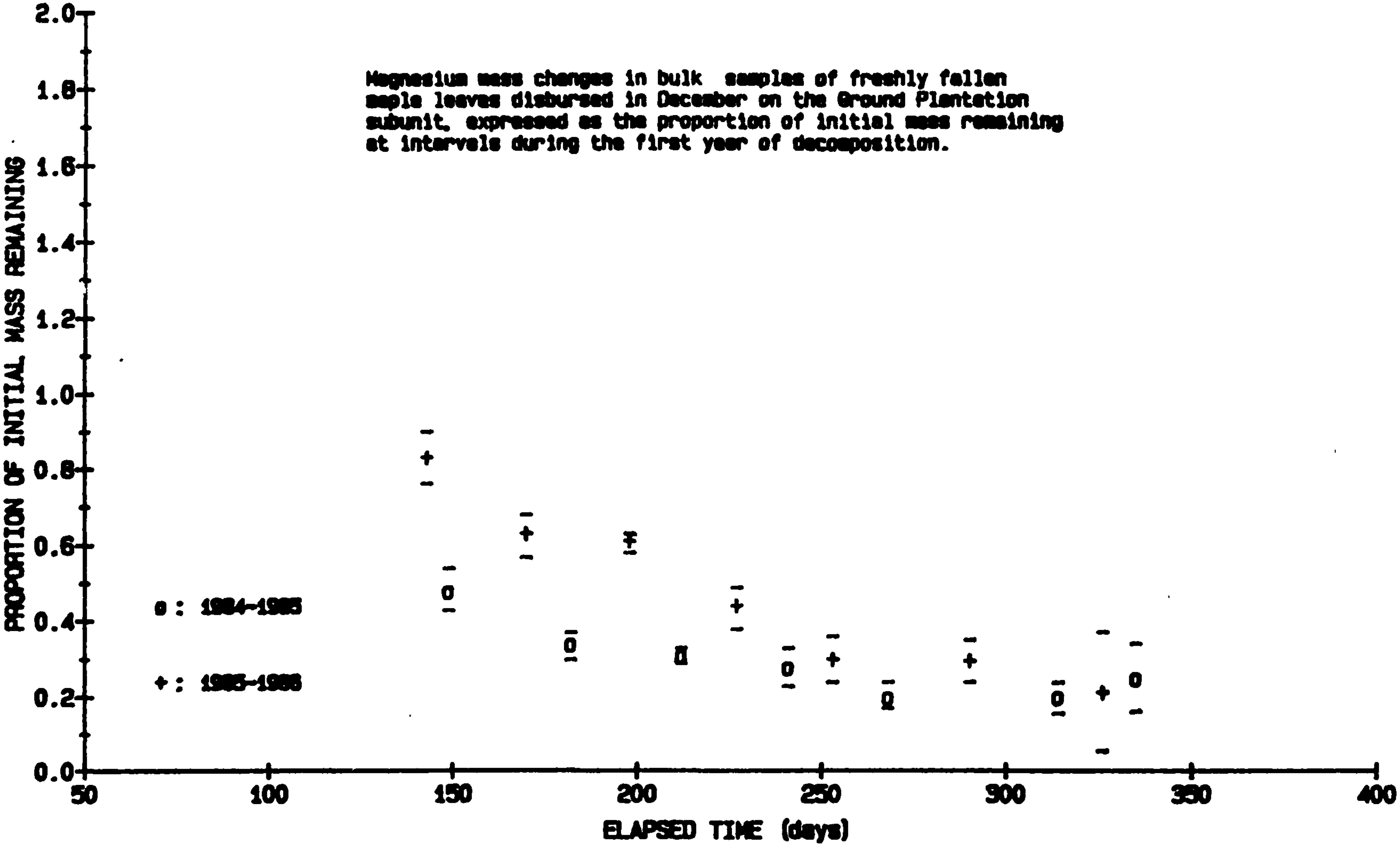


FIGURE 175.

BULK MAPLE LITTER, ANTENNA PLANTATION

PROPORTION OF INITIAL MAGNESIUM MASS REMAINING

Magnesium mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Antenna Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

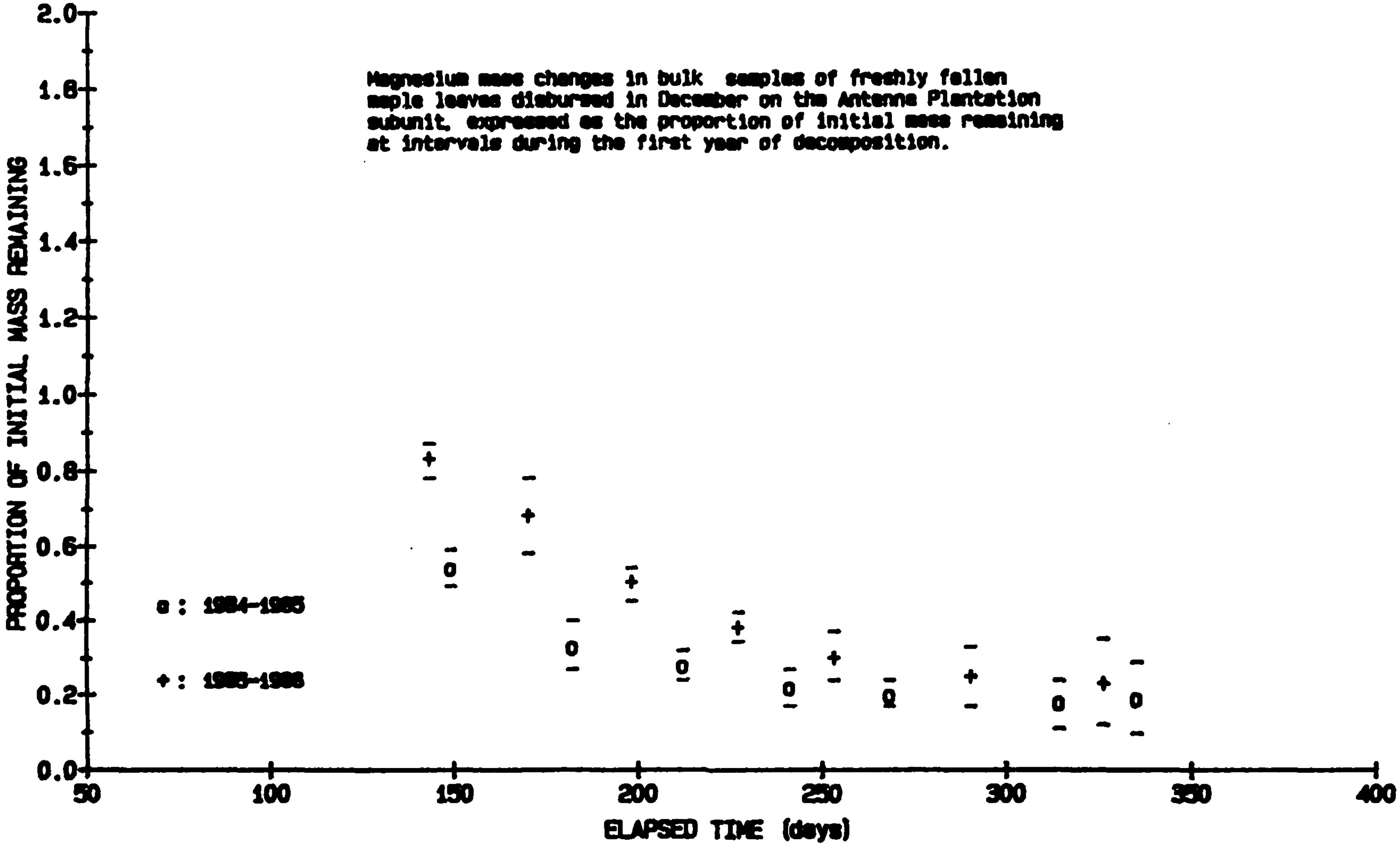


FIGURE 176.

BULK MAPLE LITTER, CONTROL PLANTATION

PROPORTION OF INITIAL MAGNESIUM MASS REMAINING

Magnesium mass changes in bulk samples of freshly fallen maple leaves disbursed in December on the Control Plantation subunit, expressed as the proportion of initial mass remaining at intervals during the first year of decomposition.

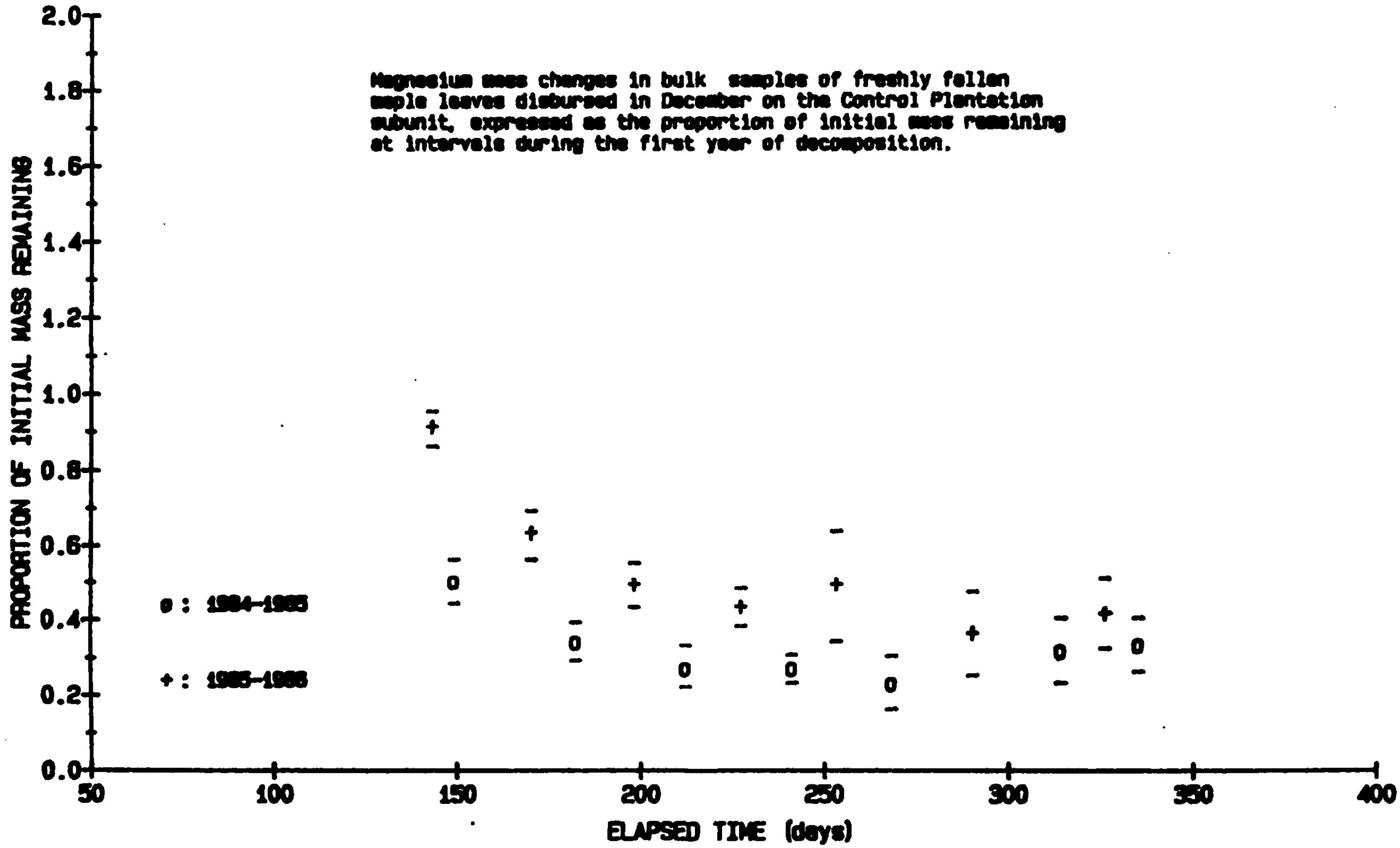


FIGURE 177.

BULK MAPLE LITTER, ANTENNA HARDWOOD STAND

PROPORTION OF INITIAL MAGNESIUM MASS REMAINING

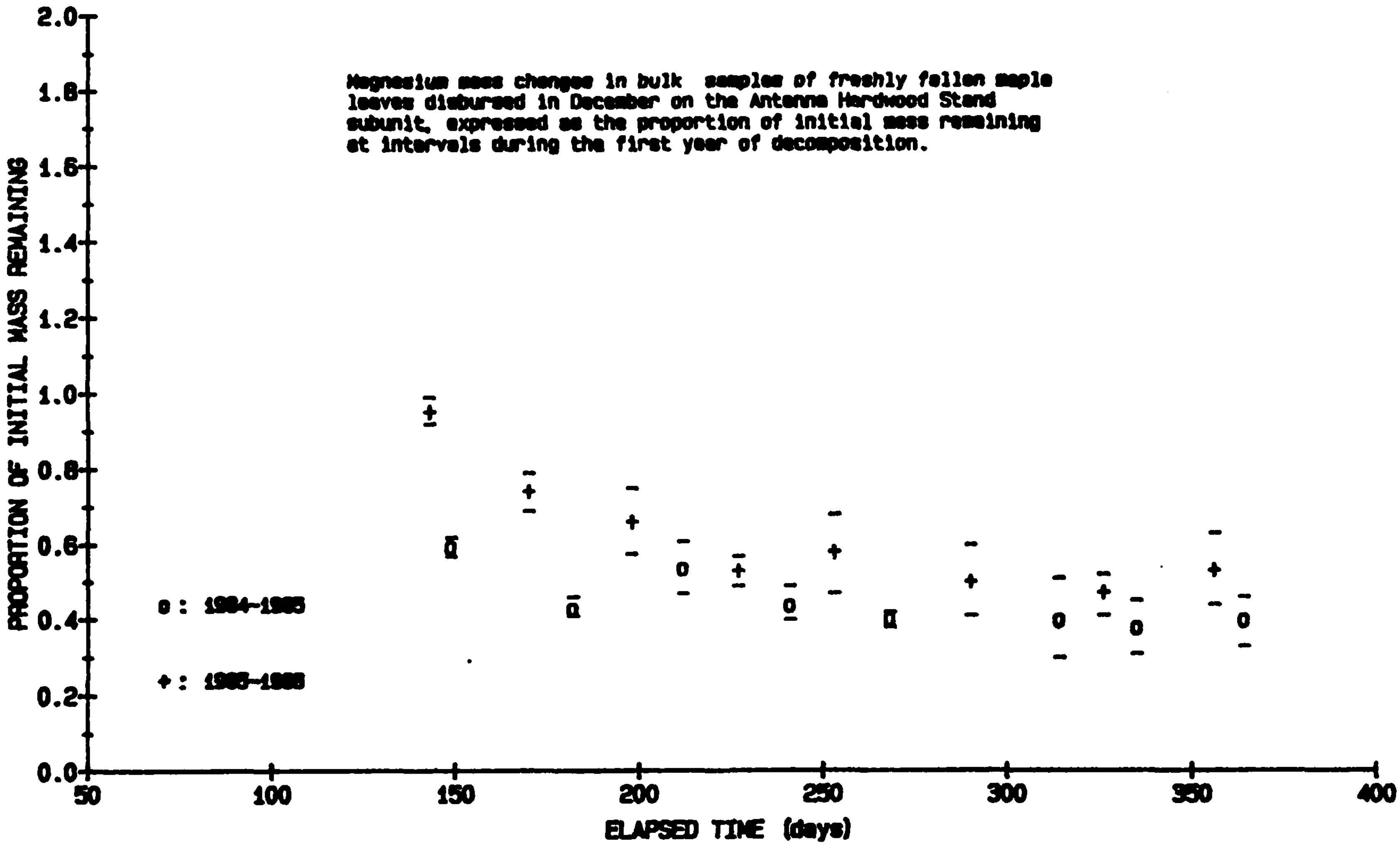


FIGURE 178.

BULK MAPLE LITTER, CONTROL HARDWOOD STAND

PROPORTION OF INITIAL MAGNESIUM MASS REMAINING

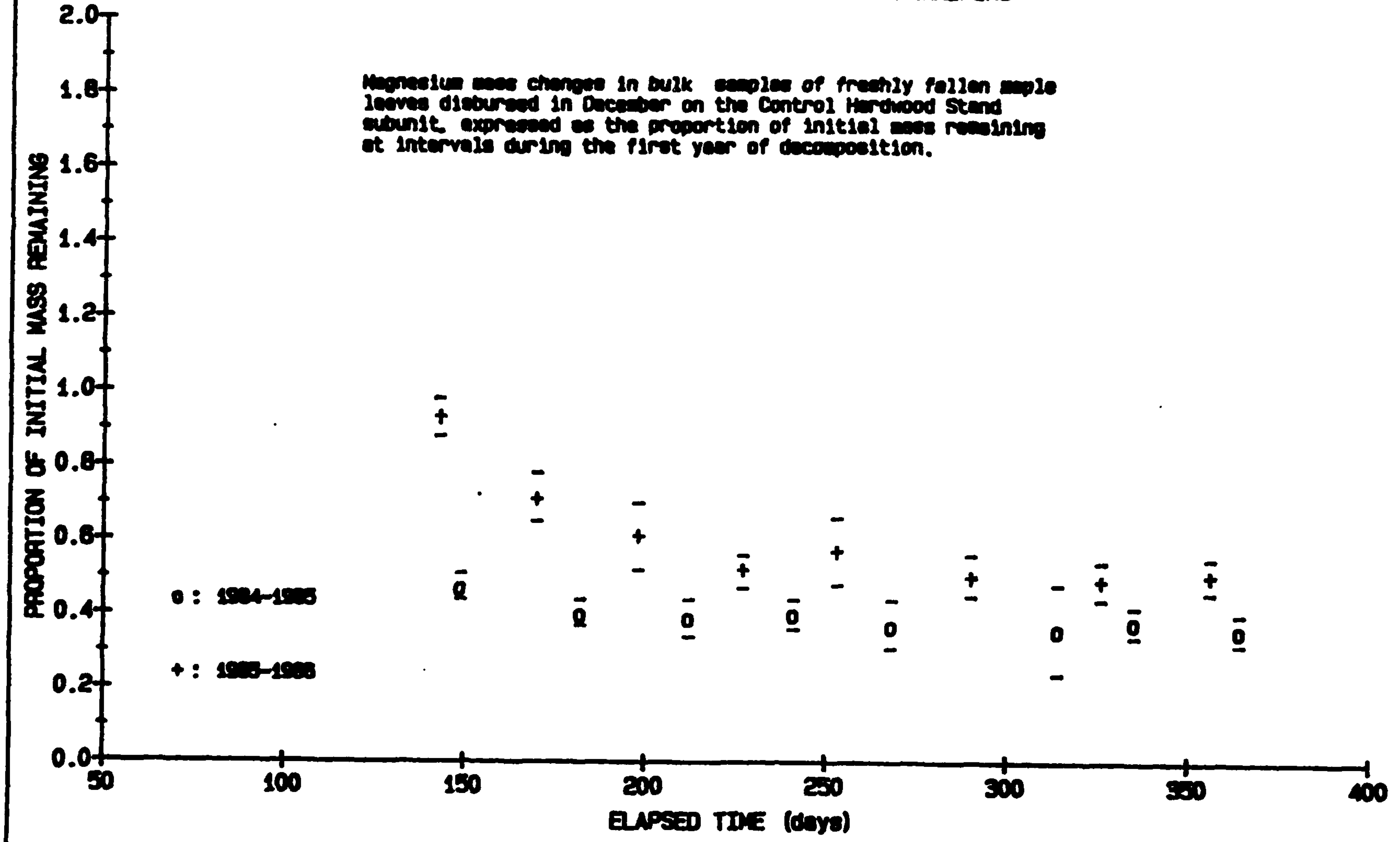


Table 132. Relationships between dry matter mass loss from bulk pine needle litter (arcsin square root of the proportion of initial dry matter mass remaining) and remaining percent nutrient mass, expressed as Pearson's product moment correlation coefficient.

Variable	Correlation Coefficient (r)					
	Plantations[a]			Hardwood Stands[b]		
	1985	1986	Combined	1985	1986	Combined
N	-0.29 0.0009[c] 126[d]	-0.37 0.0001 127	-0.24 0.0001 253	-0.65 0.0001 94	-0.57 0.0001 98	-0.44 0.0001 192
P	-0.55 0.0001 126	0.07 0.4310 127	-0.32 0.0001 253	-0.79 0.0001 94	-0.46 0.0001 98	-0.52 0.0001 192
K	0.03 0.7350 126	0.22 0.0139 127	-0.09 0.1554 253	0.22 0.0370 94	0.04 0.7130 98	-0.17 0.0175 192
Ca	-0.57 0.0001 126	-0.35 0.0001 127	-0.23 0.0002 253	-0.71 0.0001 94	-0.55 0.0001 98	-0.38 0.0001 192
Mg	0.80 0.0001 126	0.71 0.0001 127	0.35 0.0001 253	0.63 0.0001 94	-0.74 0.0001 98	0.16 0.0315 192
Ash		0.06 0.4900 127	-0.06 0.4900 127		-0.26 0.0087 98	-0.26 0.0087 98

a/ Data from the Ground, Antenna, and Control plantation subunits were included.

b/ Data from both the Antenna and Control hardwood stand subunits were included.

c/ the attained level of significance, p, for the correlation

d/ number of observations

Table 133. Relationships between dry matter mass loss from bulk oak leaf litter (arcsin square root of the proportion of initial dry matter mass remaining) and remaining percent nutrient mass, expressed as Pearson's product moment correlation coefficient.

Variable	Correlation Coefficient (r)					
	Plantations[a]			Hardwood Stands[b]		
	1985	1986	Combined	1985	1986	Combined
N	-0.23	-0.78	-0.48	-0.28	-0.45	-0.40
	.0088[c]	.0001	.0001	.0053	.0001	.0001
	126[d]	127	253	96	98	194
P	-0.49	-0.39	-0.39	-0.71	-0.56	-0.59
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	126	127	253	96	98	194
K	-0.40	-0.39	-0.35	-0.69	-0.77	-0.66
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0009
	126	127	253	96	98	194
Ca	-0.44	-0.43	-0.43	-0.42	-0.70	-0.42
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	126	127	253	96	98	194
Mg	0.41	0.66	0.54	-0.01	0.58	-0.15
	0.0001	0.0001	0.0001	0.9390	0.0001	0.0395
	126	127	253	96	98	194
Ash	-0.33	-0.48	-0.32	-0.11	-0.61	-0.24
	0.0002	0.0001	0.0001	0.2761	0.0001	0.0001
	126	127	253	96	98	194

a/ Data from the Ground, Antenna, and Control plantation subunits were included.
b/ Data from both the Antenna and Control hardwood stand subunits were included.
c/ the attained level of significance, p, for the correlation
d/ number of observations

Table 134. Relationships between dry matter mass loss from bulk maple leaf litter (arcsin square root of the proportion of initial dry matter mass remaining) and remaining percent nutrient mass, expressed as Pearson's product moment correlation coefficient.

Variable	Correlation Coefficient (r)					
	Plantations[a]			Hardwood Stands[b]		
	1985	1986	Combined	1985	1986	Combined
N	-0.70	-0.59	-0.33	-0.75	-0.26	-0.34
	.0001[c]	.0001	.0001	.0001	.0113	.0001
	126[d]	125	251	95	98	193
P	-0.56	-0.08	-0.29	-0.72	-0.11	-0.54
	0.0001	0.3485	0.0001	0.0001	0.2947	0.0001
	126	125	251	95	98	193
K	-0.16	0.33	0.11	0.33	-0.21	-0.02
	0.0724	0.0002	0.0760	0 0012	0.0380	0.8292
	126	125	251	95	98	193
Ca	0.26	0.11	0.02	0.03	-0.04	0.05
	0.0035	0.2332	0.7010	0.8088	0.6694	0.5220
	126	125	251	95	98	193
Mg	0.49	0.68	0.67	0.05	0.39	0.36
	0.0001	0.0001	0.0001	0.6227	0.0001	0.0001
	126	125	251	95	98	193
Ash	0.86	-0.32	-0.29	-0.09	-0.50	-0.52
	0.0001	0.0002	0.0004	0.7151	0.0001	0.0001
	20	125	145	19	98	117

a/ Data from the Ground, Antenna, and Control plantation subunits were included.
b/ Data from both the Antenna and Control hardwood stand subunits were included.
c/ the attained level of significance, p, for the correlation
d/ number of observations

Element 2: Red Pine Seedling Rhizoplane Streptomycetes

Introduction

Streptomycetes have been implicated in the calcium and phosphorus nutrition of ectotrophic mycorrhizae and can influence mycorrhizosphere microbial population composition through production and excretion of compounds such as antibiotics, vitamins, amino acids, and hormones (Marx 1982, Keast and Tonkin 1983, Strzelczyk and Pokojska-Burdziej 1984, Strzelczyk et al. 1987). Streptomycetes have also been found to degrade calcium oxalate, cellulose, and lignin/lignocellulose in both coniferous and deciduous litter systems (Graustein et al. 1977, Crawford 1978, Knutson et al. 1980, Antai and Crawford 1981, McCarthy and Broda 1984). The sensitivity and value of the red pine mycorrhiza studies being conducted by the Herbaceous Plant Cover and Tree Studies ("Trees") project are greatly enhanced through quantitative study of the associated streptomycete populations.

The emphasis of this element during the 1987 sampling season continued to be on the enumeration and characterization (into morphological types or morphotypes) of streptomycetes associated with the red pine mycorrhizal rhizoplane (i.e., washed mycorrhizal fine roots). As in 1985 and 1986, the mycorrhizal condition of red pine seedlings in the antenna, ground, and control plantations has been followed on a monthly basis in 1987, from May through October, by staff of the "Trees" project. Samples of the red pine mycorrhizae collected and identified from each of the ELF study red pine plantations were provided to this study for analysis of streptomycete population dynamics. As in previous years, a single mycorrhiza morphology type, designated type 3, has been studied. Type 3 mycorrhizae have predominated in all three ELF study plantations to date, probably because they are most often caused by species of Laccaria or Thelephora which occur naturally both in the study area and in the nursery from which the seedlings were originally obtained ("Trees" project, Draft Annual Report 1987, Element 6. Mycorrhiza Characterization

and Root Growth, pages 171-192).

As in 1986, six washed root samples (for macerate plate counts) were analyzed from each of the three ELF study red pine plantations. In addition to comparing data among plantations and sampling dates, the streptomycete level and morphotype data obtained during the 1987 sampling season were also compared to similar data obtained in 1985 and 1986, the only difference being that six samples per plantation were analyzed for each sampling date in 1986 and 1987 versus three samples per plantation in 1985. The capabilities of the streptomycete morphotypes recovered to degrade calcium oxalate, cellulose, and lignocellulose were also determined.

Methods

Red pine washed mycorrhizal fine root samples were collected and prepared monthly from late May to mid October at each of the control, antenna, and ground ELF study plantations, with six washed red pine mycorrhizal fine root samples examined per plantation, i.e., two independent composite samples from each of the three plots comprising each plantation subunit. The same plantation plots were sampled in 1987 as in 1986, 1985 and 1984. These samples were stored at 4°C and processed within 24 hours of receipt by the Environmental Microbiology lab in the Department of Biological Sciences. Approximately 7 days are required for processing of all field samples from the time root samples are collected in the field to the delivery of washed root samples for streptomycete analysis. All samples are refrigerated over this period of time.

Using flame-sterilized forceps, 0.1 g (wet weight) of washed roots was placed in 9.9 ml sterile buffer (0.01 M phosphate buffer, pH 7.2) and homogenized in a flame-sterilized 30 ml blender. This mixture was then transferred to a sterile, screwcap test tube. Subsequent serial dilutions were made using the same type of sterile buffer. Two larger portions of the washed roots (about 0.5 g each) were transferred to separate pre-weighed

aluminum pans and weighed; these portions were then placed in a drying oven for determination of dry weights.

As in the earlier studies, all washed root samples (after preparation and appropriate serial dilution) were spread-plated onto starch casein agar (SCA) in 100 x 15 mm petri dishes. Cycloheximide (50 mg/l) and nystatin (50 mg/l) were added to the SCA to prevent fungal growth (Andrews and Kennerly 1979, Goodfellow and Dawson 1978). Three dilutions (in duplicate) were spread-plated per sample. All plates were incubated at 20°C. Total numbers of streptomycete colonies were determined after 14 days incubation.

After enumeration, individual streptomycete colonies were characterized to determine the number of morphotypes per sample. All colonies with the same characteristics (i.e., presence/absence of diffusable pigment, presence/absence of aerial mycelium, color of aerial mycelium, and reverse colony color) were considered to represent one morphological type or strain (Keast et al. 1984). At least one colony per streptomycete morphotype was isolated in pure culture for further study. In order to evaluate the streptomycetes' contribution to mycorrhiza development and root growth, additional tests were conducted to evaluate calcium oxalate (Jayasuriya 1955, Knutson et al. 1980), cellulose (Smith 1977), and lignocellulose (Sutherland 1985) degradation. Not only the numbers but also the recurrence of distinct streptomycete morphotypes found in the 1987 samples were compared to those observed in similar samples from 1986, 1985 and 1984 to determine if some of the same types are present after the red pine seedlings have been in the field three years or more and to determine whether the same types were present at the three ELF study plantations.

Data for streptomycete levels and morphotypes based on the SCA plate counts were transformed to $\log_{10}$ (Orchard 1984). The transformed data were analyzed statistically by two-way analysis of variance to compare sampling dates and study subunits within 1987 and by three-way analysis of variance to compare years (1985 - 1987) as well as dates and plantations (Zar 1984). Wherever the

analyses showed significant differences (α = .05) between years, sites or sampling dates, Tukey's H.S.D. procedure was used to conduct multiple comparisons between years, sites and/or sampling dates (Dowdy and Wearden 1983). In addition, preliminary efforts were made to use covariates to explain differences in streptomycete levels and/or morphotype numbers among years, plantations, and sampling dates. Wherever covariance analysis detected significant differences, the results of pairwise comparisons (least square means procedure) are presented. The ability of our experimental design to detect changes in mean values for either streptomycete levels or morphotype numbers was estimated by using the 95 percent confidence interval for each sample mean (adjusted means in the case of covariance analysis) to calculate the minimum detectable change (expressed as a percentage of each sample mean). All analyses were conducted on the mainframe computer using PROC GLM of the Statistical Analysis System (SAS 1985).

Description of Progress

Detailed information on the 1987 red pine seedling mycorrhiza populations studied here can be found in the Draft Annual Report of the "Trees" project (Element 6, pages 171-192). As noted earlier, one mycorrhiza morphology type (Type 3) predominated at all three plantations during the 1987 sampling season, as has been the case since plantation establishment in 1984. Data for 1987 streptomycete levels and morphotype numbers associated with washed type 3 mycorrhizal fine roots are presented in Tables 135 and 136 as the mean, standard error of the sample mean, and minimum detectable difference between sample means based on 95 percent confidence intervals for six samples per plantation.

There was no significant difference in either streptomycete levels (p = 0.3230) or morphotype numbers (p = 0.3724) among the control, antenna and ground plantations. The relevant ANOVA statistics for levels and morphotype numbers are presented in Tables 137 and 138, respectively. However, there was a signifi-

Table 135. Mean levels of streptomycetes (x 10^5) isolated from washed type 3 red pine mycorrhizae at each of the three ELF study plantations during 1987, the standard errors of the sample means, and corresponding levels of change detectable (α = .05) 95 percent of the time, expressed as a percentage of the associated mean values.

Sampling Date	Sampling Plot								
	Control			Antenna			Ground		
	Mean[a]	S.E.[b]	%[c]	Mean	S.E.	%	Mean	S.E.	%
29 May 1987	4.0	0.57	37	3.6	0.63	45	3.8	0.60	40
23 June 1987	5.7	0.75	34	5.1	0.57	29	3.6	0.80	57
21 July 1987	4.1	0.67	42	4.6	0.84	47	5.2	0.61	30
17 Aug. 1987	6.3	0.64	26	4.6	0.84	47	4.2	0.49	30
14 Sept. 1987	6.5	0.57	23	6.8	0.67	26	6.0	0.78	34
12 Oct. 1987	1.6	0.38	63	1.8	0.11	17	1.5	0.18	30

a/ mean value for six root samples per plot, each sample representing the composited roots of 2-3 red pine seedlings

b/ standard error of the mean

c/ estimated level of population change which would be detected 95 percent of the time (α = .05), calculated as $t_{0.025,5}$ * S.E./Mean, and expressed as a percentage of the sample mean

Table 136. Mean numbers of streptomycete morphotypes isolated from washed type 3 red pine mycorrhizae at each of the three ELF study plantations during 1987, the standard errors of the sample means, and corresponding levels of change detectable (α = .05) 95 percent of the time, expressed as a percentage of the associated mean values.

Sampling Date	Sampling Plot								
	Control			Antenna			Ground		
	Mean[a]	S.E.[b]	%[c]	Mean	S.E.	%	Mean	S.E.	%
29 May 1987	3.7	0.33	23	3.3	0.42	33	4.0	0.37	23
23 June 1987	4.0	0.37	23	4.7	0.21	12	3.3	0.21	16
21 July 1987	3.5	0.34	25	3.3	0.21	16	3.2	0.31	25
17 Aug. 1987	3.5	0.34	25	3.5	0.43	31	3.2	0.31	25
14 Sept. 1987	2.7	0.33	32	3.5	0.43	31	3.3	0.21	16
12 Oct. 1987	2.5	0.22	23	3.0	0.37	31	2.7	0.33	32

a/ mean value for six root samples per plot, each sample representing the composited roots of 2-3 red pine seedlings

b/ standard error of the mean

c/ estimated level of population change which would be detected 95 percent of the time (α = .05), calculated as $t_{0.025,5}$ * S.E./Mean, and expressed as a percentage of the sample mean

Table 137. ANOVA table for detection of differences in 1987 streptomycete levels ($\log_{10}$-transformed data) associated with type 3 mycorrhizal red pine roots among the three plantation subunits, by month (May - October), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	7	3.98		21.04	0.0001	0.60
Month	5		3.92	29.00	0.0001	
Plantation	2		0.06	1.14	0.3230	
Error	100	2.70				
Corrected Total	107	6.68				

Table 138. ANOVA table for detection of differences in numbers of streptomycete types ($\log_{10}$-transformed data) associated in 1987 with type 3 mycorrhizal red pine roots among the three plantation subunits, by month (May - October), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	7	0.34		3.98	0.0007	0.22
Month	5		0.31	5.17	0.0003	
Plantation	2		0.02	1.00	0.3724	
Error	100	1.21				
Corrected Total	107	1.55				

cant seasonal effect on both levels ($p = 0.0001$) and morphotype numbers ($p = 0.0001$) at each of the three plantations. Tukey's H.S.D. multiple comparison tests of the 1987 streptomycete level data (Table 139), indicated that the May through August levels were not significantly different from each other. However, October levels were significantly lower than those of any other month. September levels were higher than any month except June. A similar, but less striking, pattern was observed for seasonal recovery of morphotype numbers (Table 140). Morphotype numbers declined in October, but even then were only significantly lower than numbers detected in May and June. Nevertheless, this general seasonal trend of the earlier sampling months having significantly greater values than the later sampling months was also observed during 1985 and 1986.

Statistical comparisons between the 1985, 1986, and 1987 streptomycete levels and morphotype numbers using ANOVA are presented in Tables 141 and 142, respectively. With both data sets, significant differences were found among years and months, but not between plantations. Streptomycete levels in 1985 and 1986 (Table 143) were not significantly different ($p = 0.8034$), but were significantly lower than the 1987 levels ($p = 0.0001$). The only month with significantly different levels was October ($p = 0.0001$). Significant differences ($p = 0.0001$) in morphotype numbers occurred between all years (Table 144). Morphotype numbers encountered in October were significantly lower ($p = 0.0001$) than those found in any other month; months which had similar morphotype numbers were nearest neighbors. The detectable difference levels for this $\log_{10}$-transformed 3-year data set as a whole were about 1% for streptomycete levels and 5% for morphotype numbers for year, month, and plantation.

Correlation analyses were conducted in order to explore relationships between seasonal estimates of streptomycete levels and morphotype numbers and other environmental and tree-associated variables. Over 30 variables relating to mycorrhizae levels, seedling growth, air and soil temperatures, pH and precipitation were analyzed in order to determine their potential

Table 139. Means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 137.

Source of Variation	Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]					
Month					1	2	3	4	5
May	5.55	0.039	1.39	May					
June	5.64	0.039	1.37	June					
July	5.63	0.039	1.36	July					
August	5.67	0.039	1.36	Aug					
September	5.79	0.039	1.33	Sept	*		*	*	
October	5.18	0.039	1.49	Oct	*	*	*	*	*
Plantation							G		A
Ground	5.55	0.027	0.98	Ground					
Antenna	5.59	0.027	0.98	Antenna					
Control	5.60	0.027	0.97	Control					

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 140. Means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 138.

Source of Variation	Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]					
Month					1	2	3	4	5
May	0.55	0.026	9.36	May					
June	0.59	0.026	8.71	June					
July	0.51	0.026	10.07	July					
August	0.52	0.026	10.03	Aug					
September	0.49	0.026	10.64	Sept		*			
October	0.42	0.026	12.31	Oct	*	*			
Plantation								G	C
Ground	0.50	0.018	7.25	Ground					
Antenna	0.53	0.018	6.84	Antenna					
Control	0.50	0.018	7.29	Control					

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 141. ANOVA table for detection of differences in streptomycete levels ($\log_{10}$-transformed data) associated with type 3 mycorrhizal red pine roots among the three plantation subunits, by year and month (<u>May - October</u>), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	9	10.05		24.06	0.0001	0.46
Year	2		2.03	21.83	0.0001	
Month	5		7.76	33.42	0.0001	
Plantation	2		0.25	2.66	0.0716	
Error	257	11.93				
Corrected Total	266	21.99				

Table 142. ANOVA table for detection of differences in numbers of streptomycete types ($\log_{10}$-transformed data) associated with type 3 mycorrhizal red pine roots the three plantation subunits, by year and month (<u>May - October</u>), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	9	3.56		30.45	0.0001	0.52
Year	2		1.53	58.90	0.0001	
Month	5		1.97	30.37	0.0001	
Plantation	2		0.03	1.02	0.3616	
Error	257	3.34				
Corrected Total	266	6.90				

Table 143. Means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 141.

Source of Variation	Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]					
Year					5	6			
1985	5.39	0.030	1.10	1985					
1986	5.40	0.021	0.75	1986					
1987	5.58	0.021	0.73	1987	*	*			
Month					1	2	3	4	5
May	5.59	0.032	1.14	May					
June	5.55	0.032	1.14	June					
July	5.50	0.032	1.15	July					
August	5.51	0.034	1.21	Aug					
September	5.52	0.032	1.15	Sept					
October	5.09	0.032	1.25	Oct	*	*	*	*	*
Plantation					G	A			
Ground	5.46	0.023	0.83	Ground					
Antenna	5.49	0.023	0.83	Antenna					
Control	5.42	0.024	0.86	Control					

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 144. Means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 142.

Source of Variation	Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]					
Year					5	6			
1985	0.72	0.016	4.37	1985					
1986	0.62	0.011	3.50	1986	*				
1987	0.51	0.011	4.20	1987	*	*			
Month					1	2	3	4	5
May	0.73	0.017	4.59	May					
June	0.70	0.017	4.79	June					
July	0.62	0.017	5.44	July	*	*			
August	0.59	0.018	5.95	Aug	*	*			
September	0.57	0.017	5.91	Sept	*	*	*		
October	0.48	0.017	7.08	Oct	*	*	*	*	*
Plantation					G	C			
Ground	0.61	0.012	3.89	Ground					
Antenna	0.63	0.012	3.81	Antenna					
Control	0.60	0.013	4.09	Control					

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

value as covariates to explain differences among years and months detected by ANOVA. Some of the variables having p values less than 0.05 and correlation coefficients greater than $|0.3000|$ were selected for the initial analysis of covariance (ANACOV) studies.

The covariates tested with 1985-1987 streptomycete levels (Table 145) and morphotype numbers (Table 146) did not completely explain the overall differences between years and months seen with the ANOVAs (Tables 141 and 142). Nevertheless, all corresponding F values were reduced considerably, and several differences between years which had been significant with ANOVA were no longer significant based on ANACOV. For streptomycete levels (Table 147), only the 1986 and 1987 data remain significantly different ($p=0.0251$). The October streptomycete levels were still significantly lower than those for all other months. Similarly, only the 1986 and 1987 morphotype numbers remain significantly different after ANACOV and fewer months had significantly different numbers (Table 148). Percent detectable differences for streptomycete levels increased modestly to between 1 and 3 percent of associated mean values. Detectable differences for morphotype numbers increased more substantially, but still remain well below 20 percent with the exception of the 1985 mean. This may be due to the smaller number of samples taken on each sampling date in 1985.

Because of the significantly lower values obtained with the October samples in all three years of data examined, additional ANOVA and ANACOV were conducted without the October data. Without the October data, no significant differences in streptomycete levels were found among months ($p = 0.4096$) or plantations ($p = 0.1405$) with ANOVA (Table 149). ANOVA without the October data (Tables 149 and 150) had little effect on the significance of differences between years seen with the October data included (Tables 141 and 143). Levels were still higher in 1987 than in 1985 or 1986. Use of the same covariates as in the earlier ANACOV did not explain the observed difference in streptomycete levels among years (Table 151). However, pairwise comparisons of the adjusted means (Table 152) showed that there was no signifi-

Table 145. Covariance analysis table for detection of differences in streptomycete levels ($\log_{10}$-transformed data) associated with type 3 mycorrhizal red pine roots among the three plantation subunits, by year and month (<u>May - October</u>), using three covariates: 1) soil temperature degree days (ST5DD; 5 cm depth, 4.4°C basis) accumulated during the 30 days prior to sampling, 2) seedling diameter (DIA), and 3) the number of precipitation events delivering at least 0.1 inch during the 30 days prior to sampling (PR.1).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	12	10.83		20.55	0.0001	0.49
Year	2		0.91	10.36	0.0001	
Month	5		3.34	15.19	0.0001	
Plantation	2		0.18	2.02	0.1353	
ST5DD	1		0.00	0.08	0.7760	
DIA	1		0.16	3.72	0.0550	
PR.1	1		0.49	11.23	0.0009	
Error	254	11.16				
Corrected Total	266	21.99				

Table 146. Covariance analysis table for detection of differences in numbers of streptomycete types ($\log_{10}$-transformed data) associated with type 3 mycorrhizal red pine roots among the three plantation subunits, by year and month (<u>May - October</u>), using five covariates: 1) soil temperature degree days (ST5; 5 cm depth, 0.0°C basis) accumulated during the 30 days prior to sampling, 2) the number of precipitation events delivering at least 0.1 inch during the 30 days prior to sampling (PR.1), 3) seedling diameter (DIA), 4) the number of type three mycorrhizae encountered on the relevant root samples (THREES), and 5) the total number of mycorrhizae encountered (MYC).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	14	3.78		21.79	0.0001	0.55
Year	2		0.33	13.42	0.0001	
Month	5		0.87	14.11	0.0001	
Month	5		0.87	14.11	0.0001	
Plantation	2		0.02	0.71	0.4936	
ST5	1		0.00	0.25	0.6152	
PR.1	1		0.06	5.20	0.0234	
DIA	1		0.04	3.06	0.0816	
THREES	1		0.03	2.37	0.1248	
MYC	1		0.04	2.95	0.0872	
Error	252	3.12				
Corrected Total	266	6.90				

Table 147. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 145.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]				
Year					5	6		
1985	5.54	0.077	2.71	1985				
1986	5.40	0.021	7.51	1986				
1987	5.51	0.042	1.50	1987		*		
Month					1	2	3	4	5
May	5.59	0.068	2.39	May					
June	5.57	0.042	1.47	June					
July	5.53	0.064	2.26	July					
August	5.52	0.064	2.27	Aug					
September	5.55	0.034	1.21	Sept					
October	5.15	0.085	3.24	Oct	*	*	*	*	*
Plantation					G	A			
Ground	5.49	0.028	1.00	Ground					
Antenna	5.52	0.026	0.92	Antenna					
Control	5.45	0.025	0.89	Control					

a/ adjusted mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 148. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 146.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]						
Year					5	6				
1985	0.71	0.159	44.00	1985						
1986	0.64	0.039	11.78	1986						
1987	0.49	0.043	17.06	1987		*				
Month					1	2	3	4	5	6
May	0.73	0.028	7.50	May						
June	0.70	0.040	11.26	June						
July	0.61	0.050	15.94	July	*	*				
August	0.58	0.049	16.50	Aug	*	*				
September	0.57	0.030	10.35	Sept	*	*				
October	0.50	0.018	7.05	Oct	*	*	*		*	
Plantation					G	C				
Ground	0.61	0.030	9.70	Ground						
Antenna	0.62	0.031	9.73	Antenna						
Control	0.60	0.030	9.86	Control						

a/ adjusted mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,n}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

Table 149. ANOVA table for detection of differences in streptomycete levels ($\log_{10}$-transformed data) associated with type 3 mycorrhizal red pine roots among the three plantation subunits, by year and month (<u>May - September</u>), and without the use of covariates.

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	8	2.20		5.24	0.0001	0.16
Year	2		1.82	17.30	0.0001	
Month	4		0.21	1.00	0.4096	
Plantation	2		0.21	1.98	0.1405	
Error	213	11.18				
Corrected Total	221	13.38				

Table 150. Means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 149.

Source of Variation	Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]					
Year						5	6		
1985	5.47	0.035	1.27	1985					
1986	5.48	0.024	0.86	1986					
1987	5.66	0.024	0.83	1987		*	*		
Month					1	2	3	4	5
May	5.59	0.035	1.21	May					
June	5.55	0.035	1.22	June					
July	5.50	0.035	1.23	July					
August	5.51	0.036	1.29	Aug					
September	5.52	0.035	1.23	Sept					
Plantation							G		A
Ground	5.54	0.027	0.95	Ground					
Antenna	5.57	0.027	0.95	Antenna					
Control	5.49	0.028	0.99	Control					

a/ mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,\infty}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, Tukey's H.S.D.

Table 151. Covariance analysis table for detection of differences in streptomycete levels ($\log_{10}$-transformed data) associated with type 3 mycorrhizal red pine roots among the three plantation subunits, by year and month (May - September), using three covariates: 1) soil temperature degree days (ST5DD; 5 cm depth, 4.4°C basis) accumulated during the 30 days prior to sampling, 2) seedling diameter (DIA), and 3) the number of precipitation events delivering at least 0.1 inch during the 30 days prior to sampling (PR.1).

Source of Variation	df	SS	Type III SS	F	Signif. of F	r^2
Model	11	3.09		5.72	0.0001	0.23
Year	2		0.90	9.22	0.0001	
Month	4		0.06	0.32	0.8662	
Plantation	2		0.15	1.48	0.2297	
ST5DD	1		0.00	0.05	0.8198	
DIA	1		0.22	4.48	0.0355	
PR.1	1		0.52	10.66	0.0013	
Error	210	10.29				
Corrected Total	221	13.38				

Table 152. Adjusted means, standard errors, detectable differences, and significantly different pairs of means, based on the model analyzed in Table 151.

Source of Variation	Adjusted Mean[a]	Standard Error	Detectable Difference[b]	Significant Differences[c]					
Year						5		6	
1985	5.65	0.090	3.11	1985					
1986	5.47	0.024	8.56	1986		*			
1987	5.57	0.049	1.73	1987					
Month					1	2	3	4	5
May	5.61	0.092	3.22	May					
June	5.59	0.040	1.39	June					
July	5.55	0.059	2.07	July					
August	5.53	0.059	2.08	Aug					
September	5.56	0.046	1.62	Sept					
Plantation							G		A
Ground	5.57	0.032	1.13	Ground					
Antenna	5.60	0.031	1.07	Antenna					
Control	5.53	0.029	1.03	Control					

a/ adjusted mean of transformed data
b/ estimated shift in the sample mean which would be detected 95 percent of the time (α = .05), calculated as $t_{.05,\infty}$*S.E./Mean, and expressed as a percentage of the sample mean
c/ α = .05, least squares means pairwise comparisons

cant difference between the 1986 and 1987 or the 1985 and 1987 levels, but that the 1985 and 1986 levels were significantly different (p = 0.0447). The borderline significance of this difference in levels between 1985 and 1986 suggests that further work with ANACOV may explain this difference.

As expected, analysis of the morphotype numbers without the October data did not affect the earlier observed significant differences between years and months.

Our preliminary work with ANACOV indicates that use of covariates may successfully explain differences among years and plantations in both the streptomycete level and morphotype number data sets. Further, because differences in levels between months were eliminated by excluding the October sampling data, tests of significance for differences among months could prove useful in the future as an indicator of ELF impact (or lack of it), especially if some measure of monthly ELF exposure such as hours of operation could be incorporated as a treatment to explain any significant monthly differences. The significance of ELF treatment could then be tested directly in the linear model.

Streptomycete morphotypes characterized on SCA throughout the 1987 sampling season from type 3 washed mycorrhizal fine roots are presented in Table 153. Similar morphotypes were found during 1987 as were detected in the 1985 and 1986 samples from the same sampling sites. Morphotypes B and F were detected at each plantation on each sampling date, and were usually found in at least two of the replicate samples per plantation, often as the predominant types. Other commonly occurring types were A, C, D, J, O, S, and T. Types E, I, L, and M were only infrequently detected in the 1986 samples and were not detected in any of the 1987 samples. No new morphotypes were detected during the 1987 sampling season. Diverse yet similar streptomycete populations appear to be established with the type 3 mycorrhizal fine roots of the red pine seedlings at all three ELF study plantations.

Streptomycete isolates from all plantations representing all 19 morphotypes (as listed in Table 153) have been tested for degradation of calcium oxalate, cellulose, and lignocellulose. Of

Table 153. Streptomycete morphotypes associated with washed mycorrhizal type 3 fine roots.

Sampling Date (1987)	Sampling Subunit[a]	Streptomycete Morphotype																		
		A	B	C	D	F	G	H	J	K	N	O	P	Q	R	S	T	U	V	W
29 May	C		X[b]		X[b]	X[b]		X		X		X				X	X		X	X
	A	X[b]	X[c]		X	X[b]		X	X	X[b]						X	X[b]			
	G	X[b]	X[b]			X[b]		X	X	X						X[b]	X[b]			X
23 June	C	X[b]	X[c]	X	X[c]	X	X	X								X[b]	X[b]	X		
	A	X[b]	X[b]	X[b]	X	X	X[b]		X[b]	X[b]	X	X[b]		X		X[b]	X[b]		X	
	G	X[b]	X[c]	X	X[b]	X[b]			X	X		X				X[b]				
21 July	C	X	X[b]	X	X	X[c]	X									X[b]			X	
	A		X[b]		X	X[c]				X			X			X[b]	X			
	G	X	X[c]			X[c]			X	X						X[b]				
17 August	C	X	X[b]	X[b]	X	X[c]	X		X		X[b]	X[b]		X		X[b]				
	A	X[b]	X[b]	X[b]	X[b]	X[b]	X		X	X	X	X			X	X[b]	X			X
	G	X[b]	X[b]		X	X[c]			X	X	X[b]					X[b]		X		
14 September	C		X[c]		X	X[c]			X	X		X					X		X	
	A	X	X[b]	X	X	X[b]	X		X[b]	X		X[b]			X				X	
	G	X	X[b]	X[b]	X[b]	X[b]			X[b]			X[b]							X	
12 October	C		X[b]	X	X	X[b]								X				X		X
	A	X	X[b]	X[b]		X[c]	X		X	X[b]		X								
	G	X[b]	X[c]	X		X[b]			X[b]			X				X	X			

[a] C - Control Plantation; A - Antenna Plantation; G - Ground Plantation
[b] detected in two or more of replicate samples/plantation
[c] predominant type in two or more of replicate samples/plantation

the 57 streptomycete isolates tested, 58% degraded calcium oxalate, 56% degraded cellulose, and 74% degraded lignocellulose. Half of the isolates, representing morphotypes B, D, J, K, N, O, Q, and T, were able to utilize all three compounds.

Analysis in 1988 will continue to deal with determination of streptomycete levels and morphotype numbers associated with washed red pine type 3 mycorrhizal fine roots. There will be no change in sampling or detection methods or in the numbers of samples analyzed per plantation. Increased emphasis will be placed on covariate analysis of the data in modeling environmental/biological variables effecting streptomycete population differences between plantation subunits, sampling dates, and years.

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Eugene M. Goodman
Biomedical Research Institute
University of Wisconsin-Parkside
Kenosha, Wisconsin 53141

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The Effects of Exposing the Slime Mold *Physarum polycephalum* to Electromagnetic Fields

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Eugene M. Goodman
Principal Investigator

Ben Greenebaum
Co-Investigator

GLOSSARY - ACRONYMS

Respiration:	The utilization of oxygen by cells to obtain energy.
QO_2	The rate of oxygen utilization: ul of oxygen consumed/minute/mg protein.
Antenna ground:	A conducting connection between the transmitting antenna and the earth.
Axenic culture:	Growth of a single organism (slime mold) in the absence of contaminating organisms such as bacteria, fungi, etc
Macroplasmodium:	A multinucleated mass of protoplasm visible to the eye; the entire structure is delimited by a plasma membrane. In the laboratory it is usually maintained on a solid substrate such as agar or filter paper.
Microplasmodia:	Plasmodia mantained in submerged shake flasks.
Submerged culture:	A method for maintaining micro-plasmodia in a liquid medium. The flask is continuously shaken to provide the culture with oxygen.
Cell cycle:	The number of hours between succesive divisions of the nucleus.
WTF:	Wisconsin Test Facility
EMF:	Extremely low-frequency electromagnetic fields

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ABSTRACT

We have previously shown that continuous laboratory exposure of the slime mold Physarum polycephalum to extremely low frequency electromagnetic fields (EMF) similar to those generated by he Navy's ELF communication system can depress the rate of respiration, and lengthen the mitotic cell cycle (Goodman et al.1976, 79, Greenebaum et al.1982). We seek to determine whether exposing Physarum to the field environment around the Wisconsin Test Facility (WTF) will induce an altered physiological state.

During the 1987 season, the laboratory data obtained by exposing Physarum for 155 days to MSK field at intensities approximating the WTF ground site failed to show significant differences in either the respiration rate or ATP levels. When these data were subjected to ANOVA's to determine whether the time a culture was out of the field was a variable to be controlled, we found that both experimental parameters were altered. These analyses also suggest that the respiration rate was affected more by the length of time a culture was out of the field than was the ATP level. Based on these results, only the first data set generated upon return from the field sites was used in assessing the bio-effects from WTF field exposure.

The data obtained from field exposure of Physarum at the WTF are generally in agreement with the lab data in that no significant differences are immediately evident. If however, the field data from weeks 10 through 13 when backup cultures were used is removed from the set, a significant effect in ATP ($p = 0.02$) is obtained. If these weeks are not removed the data is at best approaching significance at $p = 0.09$. The respiration rate is not significantly affected in either case. In examining variables such as weeks, and the type of exposure after adjusting for temperature changes, it is evident that the cultures are changing with time. Further, our analyses suggest that the change in the cultures may not be the same at all sites.

One area that requires additional investigation was the surge noted in ATP levels observed at all sites after 14 weeks of exposure. An examination of the field intensity data from the data loggers showed an apparent surge in antenna power two weeks earlier. This might suggest that culture are more responsive to short term alterations in field strength rather than long term cumulative effects. This possibility will be addressed more fully in the final report.

I. INTRODUCTION

Background: Using the slime mold *Physarum polycephalum* as an experimental system, we have shown that continuous laboratory exposure to extremely weak electromagnetic fields (EMF) ranging from 45-75 can depress the cell's ATP levels and respiration rate and lengthen the mitotic cell cycle (Goodman *et al.* 1976,79; Marron *et al.* 1986). The program described in this report attempts to address the question of whether exposing *Physarum* to the fields generated by the Navy's ELF antenna would induce similar perturbations.

To answer this question a research program encompassing both laboratory and field components was initiated in the summer of 1983. Because the WTF transmitter was not in continuous operation during 1983, most of the experimental work that year was performed in the laboratory; during this period techniques were developed for the axenic handling of cultures in the field. In the laboratory, microplasmodial cultures were exposed to a 76 Hz sinusoidal field for 15 hours/day, 5 days/week to simulate the duty cycle of the WTF transmitter at the time. The intermittent exposure regimen lengthened the mitotic cell cycle and increased the cell's respiration rate (Goodman *et al.*1984). The lengthened mitotic cycle was consistent with earlier experimental data on weak-field effects on *Physarum*; however, the increase in respiration was the inverse of our previously observed EMF effects. Based on these data and other laboratory experiments that were subsequently published (Marron *et. al.*; 1986), we concluded that the duty cycle, in addition to field intensity and frequency were factors involved in inducing an EMF bioeffect. We also exposed microplasmodia growing in the laboratory to a continuous 76 Hz Minimum Shift Keying (MSK) field. In these experiments, a small decrease in the length of the mitotic cell cycle was observed; no differences were observed in the respiration rate.

Macroplasmodia growing on agar and exposed to weak EMF at the ground (G) and antenna (A) sites of the Wisconsin Test Facility (WTF) during 1984 showed an increase in their mitotic cell cycle relative to controls. Although these data appeared to be significant and in agreement with our laboratory studies, the increased length of the control's cell cycle was not consistent with earlier laboratory experiments. EMF (Goodman *et al.*;1976). The lengthening of the WTF control cell cycle prompted us to examine our handling procedures to determine whether our protocols might be affecting the outcome of our studies.

In the 1985 season we instituted several procedural changes, particularly in the way EMF exposed macroplasmodia were transported from the test site to the laboratory at UW-Parkside. In addition, we began to examine ATP as an alternative, experimental parameter. ATP was included in the study because other data suggested it might be a more sensitive indicator of an EMF effect. Further, by substituting the ATP determination for mitosis, we eliminated both the requirement for someone to visually assess mitosis and the possibility of introducing a "scoring bias" by the technician making the measurements. We also changed the protocols used to re-establish microplasmodial suspension cultures from the agar-based macroplasmodium used for field exposure. The data obtained from the WTF during the 1985 season, indicated no significant changes

were found in ATP levels, respiration rate, or the length of the mitotic cell cycle. Although significant alterations were not observed we were unable to conclude that exposure to WTF fields had no significant effect because of the reduced duty cycle of the antenna during 1985.

During 1985, experiments with continuously exposed microplasmodia in the laboratory also failed to reveal significant differences in either QO_2 or ATP. The absence of differences in ATP levels between exposed and control plasmodia may in part be due to the low number of experiments performed. We interpret the absence of significance in the QO_2 experiments with microplasmodia exposed to 76 Hz MSK 17.5 uT as indicating that we are below the threshold for this parameter. This suggestion is supported by a more recent set of EMF experiments using *Physarum* amoebae exposed to 60 Hz, 0.1 mT. In these experiments, the amoebae's ATP levels were depressed 8-11% whereas their respiration rate was not affected (Marron *et al.*;1986)

The antenna became almost fully operational for the 1986 season. In the laboratory aspect of the program, the applied fields were decreased to approximate the magnitude of the electric fields and current densities that would be encountered at the WTF-ground site. The data collected from both the field and lab did not appear to be statistically significant. One question raised on the analyses of the 1986 data concerned the multiple number of experiments performed on a weekly culture and whether we were artificially increasing the N of our data. Another problem concerned the fact that after September 1, samples were collected and analyzed on a biweekly basis rather than weekly.

In 1987, we again adopted several modifications to our general protocols. The most important change involved the length of time cultures were maintained as microplasmodial suspension culture after removal from the WTF. All samples were analyzed *twice*; the first analysis was performed as soon as vigorously growing submerged cultures were established (approximately 40-72 hrs after returning to U.W. Parkside) and the second between 96-136 hours. The rationale for performing each analysis twice was an attempt to insure comparability of the data at the end of the field season. For example, in past years we found that the conversion of macroplasmodia to microplasmodia sometimes required more than 72 hours; this was especially true toward the latter part of the field season, i.e. September and October. Since this problem would not be evident until the end of the field season, we decided to run two experimental data sets. The first data set was acquired 2-3 days after field exposure and the second within 6-7 days. At the end of the season, the data set that was most consistent, that is *either* the 2-3 day or 6-7 day data sets would be analyzed. Since no problems were encountered in establishing suspension cultures during the 1987 filed season, we focused primarily on the first data set. The second set was used in supplemental analyses, primarily as a way of examining the consistency of the data and to validate our procedures for backup cultures.

II. CONTROL AND EXPERIMENTAL SITES

The same three sites used in the 1986 field studied were employed in 1987 (1 control and 2 experimental or exposure sites). The first site is located parallel to the west ground (G); the second (A) is located about 3 miles from the ground site below the overhead cables of the antenna; and the control (C)

is located about 20 miles east of both experimental sites. At each site, three cultures were exposed to the ambient magnetic field of the antenna. In addition, two cultures were exposed to an E-field adjusted to match the electric field in the nearby soil. At the third site, cultures were exposed to a current density matched to that of the nearby soil.

We attempted to make two field measurements at each site on a weekly basis. However, there were occasions when the antenna was either not operational when transfers were being made, or we encountered problems with our measuring equipment or the site had been perturbed and the electrodes were disconnected. Several measurements at the Control site were not made because they were below the detectable resolution of our instruments.

The first measurement was made before the "old" cultures that had been growing for the previous week were removed; the second measurement was made after the "new" cultures had been subcultured and placed back in the ground. The field measurement data are found in Appendix A, Tables 1,3 and 5; the calculated current density and E-field at each site are found in Appendix A, Tables 2, 4 and 6. Since E-fields were adjusted at the time the cultures are placed back into the ground, a comparison of the weekly data provide a means of assessing the change or drift in field conditions after a week of exposure. Unfortunately, this approach provides only a static picture of the field status throughout the week. To address this situation IITRI installed a data collection system at each site to monitor the fields on an hourly basis, 24 hours/day. These data were not used in the initial analyses of data in this report but may be used in the final report if exposure is deemed a relevant variable.

III. PROTOCOLS FOR FIELD EXPOSURE AND MAINTENANCE OF PHYSARUM:

A. Field Exposure System: Physarum macroplasmodia were placed in the field on May 23, 1987 (Day-1) and maintained there until October 17, 1987 (Day-148). Cultures were maintained in autoclavable polyethylene chambers (7" x 4" x 2 1/4") with a tight fitting top; two stainless steel electrodes were placed 6" apart and about 1/4" from the bottom of the chamber. Each chamber was filled with 150 ml of an agar growth medium. The growth chambers were placed inside a protective chamber (10" x 10" x 20"); a tight fitting lid provided a reasonably waterproof environment for the cultures. A 1/2" U-shaped vent was attached to the lid of the outer chamber to facilitate gas exchange. On several occasions, the vent pipes were separated from the outer chamber, presumably by animals. When the latter occurred, the plasmodia were generally contaminated and backup cultures were used. The protective chamber containing the growth chamber was placed in a hole about 20" x 20" x 20"; 8" square copper collector plates were buried 1 meter from the hole along a line with the predominant electric field. Electric fields were brought to the growth boxes by buried wire leads that ran from the collector plates to a plug on the outer wall of the protective chamber. To protect the exposure system, each hole was covered with a plywood board. Each site contained three exposure systems; two were used for E-field exposure and the third for examining the effects of current density. Temperature was monitored by placing battery-operated Dickson monitors inside one of the protective chambers. The monitors were calibrated in the lab prior

to their use in the field. These recorders generally performed satisfactorily except when the vent pipes were broken and water got into the chamber. A monthly temperature summary for the season is shown in Appendix B. The temperature at the control site tracked about the same as both experimental sites through most of the season; during October, the temperature at the control site was about 1 °C higher than either experimental site. In 1986, temperature at the Control site was slightly lower that the experimental sites.

B. **Culture Maintenance**: Physarum was maintained in the field on an agar substrate using the growth medium of Daniel and Baldwin (1964) diluted to half strength with water, sterile rolled oats (1 % w/v) and 3 % agar. All media preparation and sterilizations were performed at U.W. Parkside; growth containers were placed in sterile plastic bags and transported to the exposure site. Growth chambers were held at the WTF for a week in a Plexiglas chamber fitted with a bank of timer-controlled uv lights. The uv lights were turned on for 10 minutes every night. These precautions allowed us to identify any growth boxes that became contaminated during transport and decreased the chance of introducing contamination from an exogenous source. From May 23 through the October 17, agar cultures of Physarum were transferred on a weekly basis. This represents a change from previous protocols when transfers were made weekly until September and then biweekly until the experiment was terminated.

The following protocols were followed to transfer cultures in the field: (1) The outer chambers were disconnected from the collector plates (after making field measurements) and brought to the mobile lab. The outside of the container was thoroughly washed to remove mud and debris before being brought into the mobile lab. (2) The growth chambers were removed from the outer protective containers and their outer surfaces thoroughly cleaned using a disposable wipe saturated with Zorbicide. (3) The growth chambers were placed in a laminar flow hood and a 2.5 cm^2 piece of plasmodium was removed from the outer edge of the growing culture and transferred to a new growth chamber. (4) The growth chamber was placed in the protective container and returned to the field.

The remaining field-exposed macroplasmodia in the growth chamber were returned to U.W. Parkside; at the airport security station, cultures were always examined by hand rather than by the X-ray scanners. Upon returning to the lab, the macroplasmodia were scraped from the agar surface and placed in a 125 ml Erlenmeyer flask containing a 50% solution of sterile growth medium and water; the flask was then placed on a shaker. Microplasmodia were re-transferred to full strength medium within 14 hours and maintained as microplasmodial cultures in 125ml Erlenmeyer flasks until growth was adequate to measure respiration and ATP levels. In most cases experiments were performed within 40 to 72 hours after removing the cultures from the field. Microplasmodia from field-exposed and control sites were grown on the same shaker in the laboratory. Once a suspension culture had reached vigorous growth, a 0.2 ml aliquot from each control and experimental site was placed on Petri plates (containing 1/2 strength agar-growth medium) and placed in an incubator at 26°C. These cultures were used as backups on the ensuing weekly trip in the event a particular site had a contamination problem. If these cultures were used as backups, they would have been out of the field a total of 7 days. During August of the 1987 season, we used the backup cultures twice at the Control site, (once at the E site and once at the J site) and once at the

Antenna site(both E and J sites). With these exceptions, cultures of Physarum were continuously exposed to their appropriate environments for 148 days. On occasion we also encountered laboratory contamination problems in the process of converting WTF field-exposed macroplasmodia back to shake flask microplasmodia. These instances appear as blanks in the data summary sheets of Appendix C.

C. Laboratory Handling of Physarum:

1. Growth: In the laboratory macroplasmodia were grown in chambers identical to those used at the WTF. The temperature in the exposure incubator was adjusted weekly to match the average weekly temperature recorded the previous week at the ground site. Temperature in the control incubator was set according to the previous week's average temperature at the control site. The methods employed to measure both respiration and ATP in the laboratory were the same as those described for WTF-exposed cultures.

2. Electromagnetic Field Environment in the Laboratory:

Both ambient magnetic fields and those generated by the exposure apparatus built into the incubators in the laboratory were assessed by IITRI and monitored periodically by the investigators. As a result of applied and ambient field measurements in the laboratory by the IITRI team on May 24, 1987, several adjustments in the applied fields were made to ensure that the laboratory cultures' environment was as close as possible to that at the ground site at the WTF. The choice was made to emulate the ground site because that site has the highest electric field, and until very recently the general wisdom in much of the bioelectromagnetic community has been that the electric, rather than the magnetic fields are the element of chief concern. These changes included turning the No. 1 incubator 90° in order to minimize crosstalk between it and the other locations.

In the year ending October 30, 1987, the experiments used applied fields that differed from those described in the 1984 IITRI report, although the ambient fields remain the same. Applied magnetic fields continued to be monitored by the UWP team using both the Bell Model 640 Hall-Effect Gaussmeter and a Monitor Industries (Boulder, Colorado) Model 42A-1 gaussmeter, operating on the principle of detecting the field induced in a 15 cm dia. coil, that was sensitive to 5×10^{-8} T (full-scale on most sensitive scale). The two were cross-calibrated periodically at the 0.1 mT level. The Monitor gaussmeter has a flat frequency response in the ELF region and reads total rms field strength; the signal waveform was always displayed on an oscilloscope to check on its frequency and determine whether there were significant higher harmonics. Electric fields continued to be applied using the technique of applying a voltage directly across the culture medium; the field strength in this instance can be directly calculated. Earlier reports have discussed our direct measurements of electric field strength that have confirmed these calculations.

In 1986-87 the No. 3 incubator continued to be used for exposures to a 76 Hz MSK-modulated signal produced by the standard IITRI-supplied generator and amplified by the Elgar amplifiers. The control incubator for these exposures was a located in the adjoining room; dummy loads to simulate the electric field-exciting network were connected to the control cultures' growth chambers.

Fields in the exposure chamber were adjusted to simulate the fields at the Wisconsin Test Facility. The 76 Hz MSK magnetic field was 0.7 ($\pm$ 0.1) uT. Two rectangular (18 x 9.5 cm) culture chambers were used, with electric potential applied across parallel electrodes at opposite ends of the chamber to create an electric field parallel to the long dimension. In one chamber the culture was exposed to an electric field equal in magnitude to that in the earth at the WTF; in the other the exposure was to a current density equal to that in the earth at the WTF. The difference in conductivity between earth and the culture medium meant that both electric field and current density in the earth could not be duplicated simultaneously. The situation in the laboratory duplicated the situation in the test chambers at the WTF, where separate chambers were set up at the earths electric field intensity and at the earth's current density. The electric field-matching chamber was set to 0.8 V/m (0.16 A/m^2); the current density-matching one to 0.01 V/m (0.002 A/m^2).

Ambient fields in the two incubators of interest may be taken from the above-mentioned 1987 and previous IITRI measurements. The measurements were taken with the No. 1 incubator in its old location, but they give an indication of the general magnitude of the ambient fields. With the No. 1 incubator in its new position, the IITRI-measured values for crosstalk between the 60 Hz being applied in No. 1 as measured in No. 3, were reduced to below room ambient (0.1 uT). The general level of ambient magnetic field, including crosstalk, in No. 3 incubator at the location of the two culture dish positions used in this year's experiments ($/B^2/$) was 0.1 uT; since the harmonic content was quite small, the frequency was almost entirely 60 Hz. In the control incubator, the ambient magnetic field intensity was 0.5 uT, again essentially all at 60 Hz.

An additional ambient field measurement was made at the moving table of the shaker upon which exposed and control microplasmodia were placed during the cultures conversion to suspension growth and during laboratory experimentation. Since this position was near No. 1 incubator, some crosstalk from its 60 Hz magnetic field generating coils was detected; addition of magnetic shielding material reduced the fields by a factor of two to a level of 0.15 uT. In addition the shaker motor generated a 0.3 uT magnetic field at essentially 60 Hz. The net magnetic field magnitude was measured to be 0.3 uT.

IV. EXPERIMENTAL OVERVIEW

A. RESPIRATION: The rate of oxygen consumption is expressed as the QO_2 (ul of oxygen consumed /min / mg protein). A measurement is made by placing a 1.0 ml aliquot of microplasmodia and 2.0 ml of aerated growth medium into the water jacketed reaction vessel (YSI model 53) maintained at 25.8 °C. The system was closed by placing a calibrated oxygen probe into the reaction vessel, and allowing it to equilibrate for 5 min. Oxygen consumption was measured over the next 2-3 minute period. Triplicate respiration measurements were made on each culture. In some cases insufficient microplasmodia only allowed us to perform duplicate measurements. After withdrawing a sample for analysis, the flask was returned to the shaker; the latter is a slight modification to the protocols used in previous years and may account for the higher QO_2's reported this year. To facilitate normalization of the data, microplasmodia were removed from the vessel after completing the respiration measurement, the yellow pigment was removed by trichloroacetic acid-ethanol, and the pellet was dissolved in NaOH.

Duplicate Biuret assays performed on each sample to determine their protein content. A new standard curve was constructed for each protein data set. The data in Appendices C (field data) and D (lab data) represent the normalized averages of the daily measurements for a given exposure regimen.

B. ATP: To extract ATP from microplasmodia, duplicate 1.0 ml samples were removed from the shake flasks and placed in tared polycarbonate tubes containing 2.5ml Tris-borate buffer (pH 9.2) that had been brought to 98 °C in a boiling water bath. The tubes were capped with a marble and the ATP was extracted for 15 min. Following extraction, the tubes were removed, wiped to remove exterior moisture and weighed. The weight was used to ascertain the final volume of the extract. The extracts were centrifuged at 84,000g. The supernatants were used for ATP analysis; NaOH was added to solubilize the pellet and duplicate Biuret assays performed to determine its protein content.

V. DATA ANALYSIS

A. Methods: The lab data was analyzed to consider four effects, the effect of replication of measurements (REP), the effect of hours in the microplasmodial suspension culture (HOURS), the effect of exposure type (EXP) and the weeks of exposure (WEEKS). Two analyses of variance (ANOVA's) were performed, one to examine the effects of replication (REP) and HOURS along with their interactions with EXP and a second to examine the effects of WEEKS and EXP. In the second case, the lack of replication prohibited consideration of the interaction of these factors in the lab data.

To evaluate the appropriateness of an ANOVA for this and subsequent analyses, autocorrelations for the outcome variables of the laboratory data were evaluated. The absence of significant auto-correlations indicated that the analyses could be viewed as independent measurements. Based upon these results, ANOVA's were used in the final analyses. Similar autocorrelations were evaluated for the field data along with lagged cross-correlations with three temperature variables. The temperature variables were derived from high and low temperatures recorded for each day of the study at each site. Two of the temperature variables were weekly averages of these daily extremes. The mean weekly temperature was estimated using the average of these two values. This analysis was used to determine the best measure of temperature for use as a predictor of the two outcome variables. The mean weekly temperature with a lag of zero proved to be best suited for this task.

Adjustment for the association of temperature with the two outcome variables was performed using a simple linear regression procedure. The residuals from this regression served as the independent variables for a multivariate ANOVA. This ANOVA included exposure type (TYPE), exposure site (SITE), and weeks of exposure (WEEKS) and their two-way interactions as predictor variables with ATP and Q02 as separate outcome variables. Type refers to either the E-field (E) or current density (J).

On the tenth week of field exposure, back-up cultures were used to replace some contaminated cultures in the field. The analysis of the lab data suggested that time in the laboratory may alter the characteristics of the culture. Therefore, in addition to the above analysis, an ANOVA was performed

which excluded data points for the month following the introduction of back-up cultures.

B.RESULTS: Tables 1 and 2 summarize the ANOVA of the laboratory data. We see here that time in the lab has a significant effect on the respiration rate of the culture. A review of the means suggests that respiration rates decline with time (a least significant difference analysis bears this out). ATP levels are less affected by time in the lab, but do tend to show an increase as measurements are replicated. The replication effect does not interact significantly with exposure type. In light of this, the small effect of replication was not judged to be sufficient to preclude averaging of the replicated values. Because time in the lab shows an interaction with exposure type, only the first of the measurements recorded after return to the lab from the field were used in the following analyses.

An analysis of the effect of week and exposure in the laboratory data is shown in table 3. The culture parameters changed significantly over time for all variables. This change did not seem to follow any ordered pattern as demonstrated in the plot of the data shown in figures 1 and 2. This finding argues against the presence of a cumulative effect for length of exposure. The level of exposure was not significant for any of the outcome variables. This can be clearly seen in figures 2 and 3.

Finally, tables 4 and 5 show the ANOVA's for the field data. The effect of the site was only significant when weeks 10 through 13 were removed. The effect of time is strongly significant for respiration rates, while this effect is marginally significant ($p=.05$ and $p=.06$) for ATP levels. In neither case is a steady increase in effect observed with time. This result argues against the notion of a cumulative effect of time. The interaction of site and week is marginally significant for QO_2 when the entire data series is considered ($p=.05$). Type of exposure is also significantly related to respiration rates in both the complete and the edited data set. All field data are plotted in Figs. 3-7.

It should be stressed that these analyses are somewhat liberal in that any autocorrelation in the data would tend to reduce the effective degrees of freedom for the analysis and would therefore increase the observed p values. For this reason, one can feel comfortable that those parameters excluded by this analysis are not significantly related to the outcome variables. Those factors included by the analysis should be considered carefully and will be studied more fully in the final report in which all field data will be considered.

The ATP data also deserve further consideration. We can see from the means provided and from Fig. 6 that the culture near the antenna consistently demonstrated the highest values for ATP while the ground site was generally between the two for E-field exposure. Of particular interest is a spike in the data at week 14. Two weeks before this time, the antenna produced the largest surge of power of the entire summer. This observation suggests that the observed effects may involve short term responses to field strength rather than long term cumulative changes. It also raises the possibility that high power have a pronounced effect which is not seen at the lower power levels of normal antenna operation. This possibility will be addressed more fully in the final report.

VI. CONCLUSIONS

The laboratory data obtained by exposing Physarum for 155 days to MSK fields at intensities approximating the WTF ground site failed to show significant differences in either the respiration rate or ATP levels. When these data were subjected to ANOVA's to determine whether the time a culture was out of the field was a variable to be controlled, we found that both experimental parameters were altered. These analyses also suggest that the respiration rate was affected more by the length of time a culture was out of the field than was the ATP level. Based on these results, only the first data set generated upon return from the field sites was used in assessing the bio-effects from WTF field exposure.

The data obtained from field exposure of Physarum at the WTF are generally in agreement with the lab data in that no significant differences are immediately evident. If however, the field data from weeks 10 through 13 when backup cultures were used is removed from the set, a significant effect in ATP ($p = 0.02$) is obtained. If these weeks are not removed the data is at best approaching significance at $p = 0.09$. The respiration rate is not significantly affected in either case. In examining variables such as weeks, and the type of exposure after adjusting for temperature changes, it is evident that the cultures are changing with time. Further, our analyses suggest that the change in the cultures may not be the same at all sites.

One area that requires additional investigation was the surge noted in ATP levels observed at all sites after 14 weeks of exposure. An examination of the field intensity data from the data loggers showed an apparent surge in antenna power two weeks earlier. This might suggest that culture are more responsive to short term alterations in field strength rather than long term cumulative effects. This possibility will be addressed more fully in the final report.

Table 1. Results (p values) of ANOVA of lab data for effects of replication and time in lab.

TYPE		REP	EXP*REP	HOURS	EXP*HOURS
E-FIELD					
	QO2	.73	.26	.0001	.01
	ATP	.01	.59	.22	.49
C-DENSITY					
	QO2	.89	.41	.0001	.04
	ATP	.001	.63	.05	.12

Table 2. Descriptive statistics associated with relication and hour effects.

		MEAN	STD.DEV	STD.ERR.
REPLICATION:				
ATP	1	15.3	5.47	.77
	2	16.8	4.69	.68
QO2	1	0.728	0.198	0.026
	2	0.720	0.194	0.026
	3	0.725	0.188	0.025
HOURS:				
ATP	48	15.7	5.70	1.31
	72	18.2	8.01	2.41
	96	15.7	2.44	0.577
QO2	48	0.806	0.192	0.042
	72	0.719	0.158	0.044
	96	0.644	0.180	0.039

Table 3. Results (p values) for ANOVA of EXPOSURE and WEEK effects in laboratory data for 1987.

	EXPOSURE	WEEK
RESPIRATION RATE	.79	.0001
ATP LEVELS	.30	.0001

Table 4. Results (p values) from the ANOVA of the 1987 field data.

EFFECT	QO2	ATP	QO2 (Weeks 10-13 excluded)	ATP (Weeks 10-13 excluded)
SITE	.15	.09	.77	.02
WEEK	.0001	.05	.0001	.06
TYPE	.02	.91	.03	.55
SITE*WEEK	.05	.07	.14	.24
SITE*TYPE	.37	.47	.47	.77

Table 5. Means from 1987 field data.

TYPE	MEAN	STD.DEV	STD.ERR.
E-FIELD:			
ATP			
CONTROL	13.3	4.44	1.15
GROUND	14.3	3.57	.924
ANTENNA	16.0	5.48	1.37
QO2			
CONTROL	.780	.146	.038
GROUND	.793	.146	.038
ANTENNA	.762	.128	.032
C-DENSITY:			
ATP			
CONTROL	15.0	3.56	.953
GROUND	13.3	2.56	.739
ANTENNA	15.5	4.56	1.14
QO2			
CONTROL	.794	.165	.044
GROUND	.712	.178	.051
ANTENNA	.702	.129	.032

Figure 1

ELF 1987 lab DATA ANALYSIS

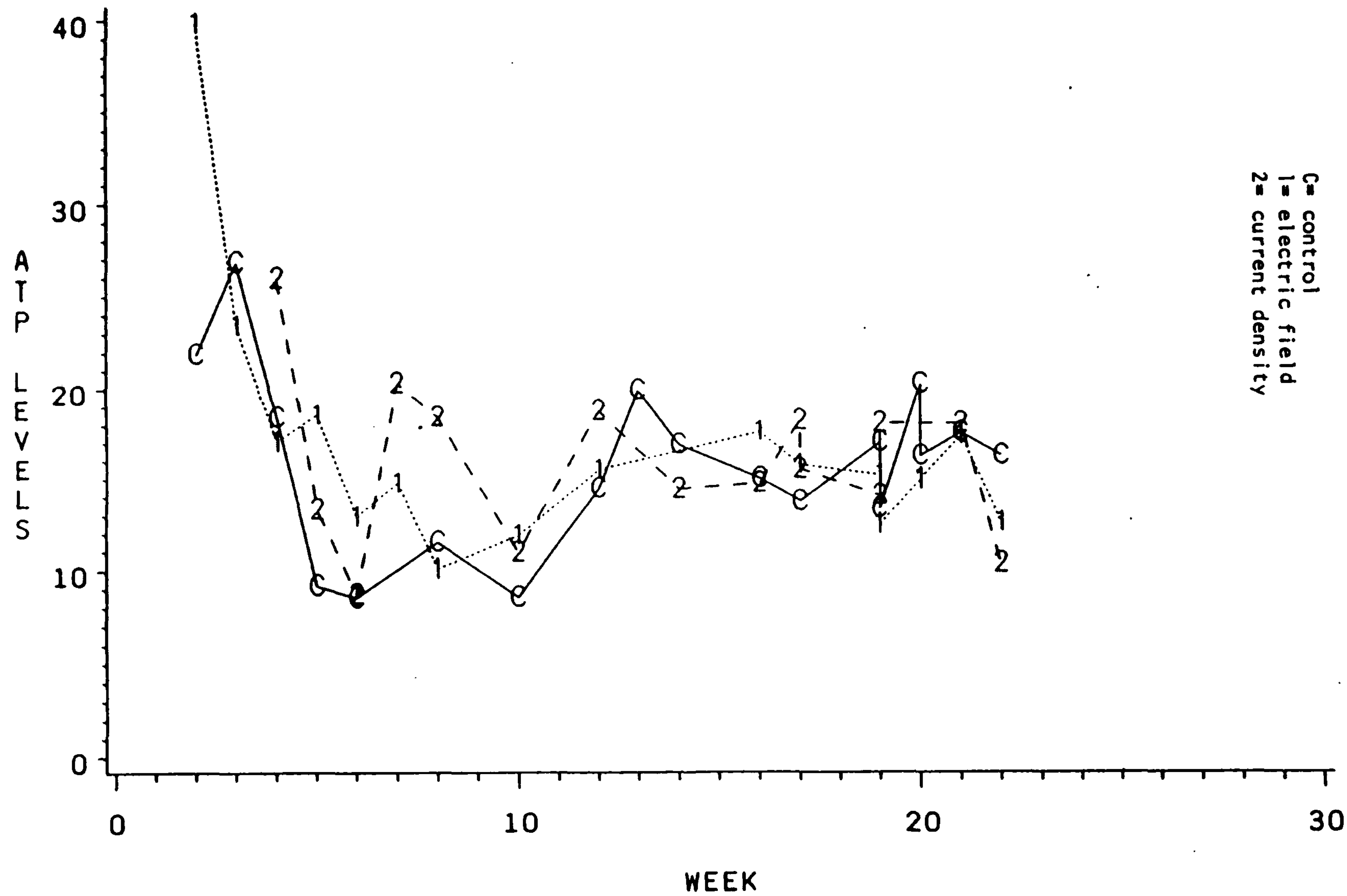
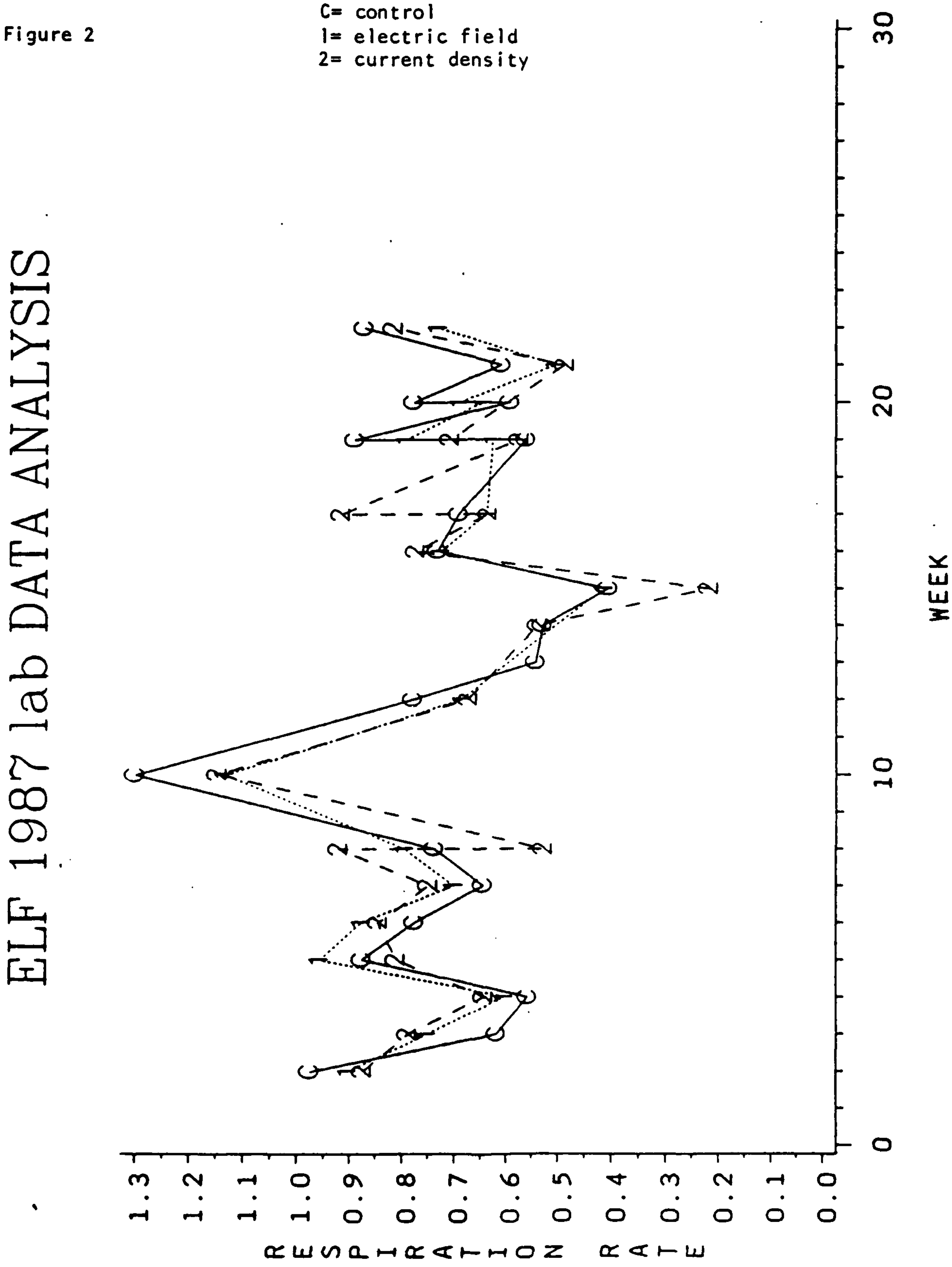


Figure 2


C= control
1= electric field
2= current density
ELF 1987 lab DATA ANALYSIS
RESPIRATION RATE
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
WEEK
0
10
20
30

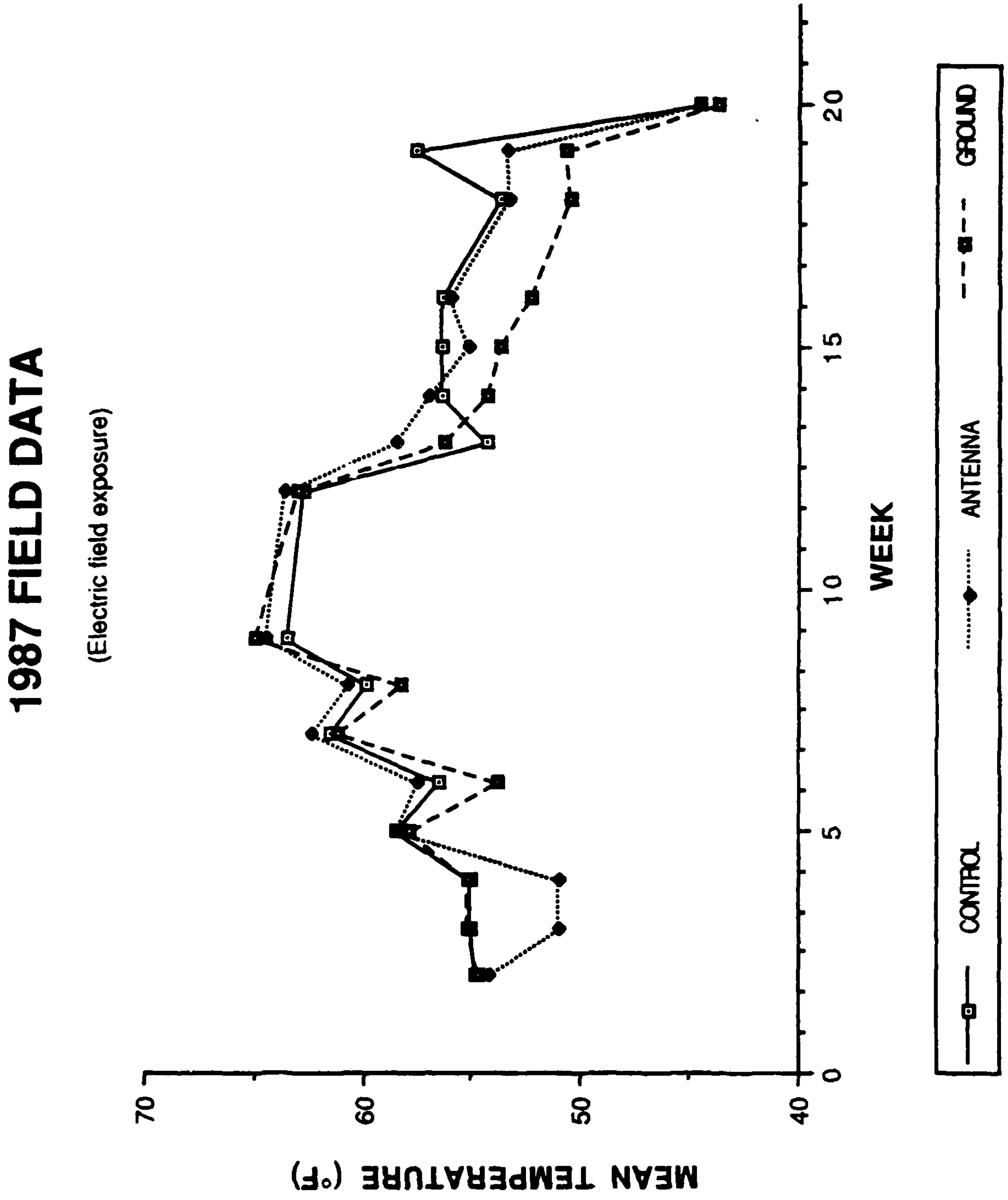

1987 FIELD DATA
(Electric field exposure)
MEAN TEMPERATURE (°F)
70
60
50
40
0
5
10
15
20
WEEK
CONTROL
ANTENNA
GROUND

Figure 3

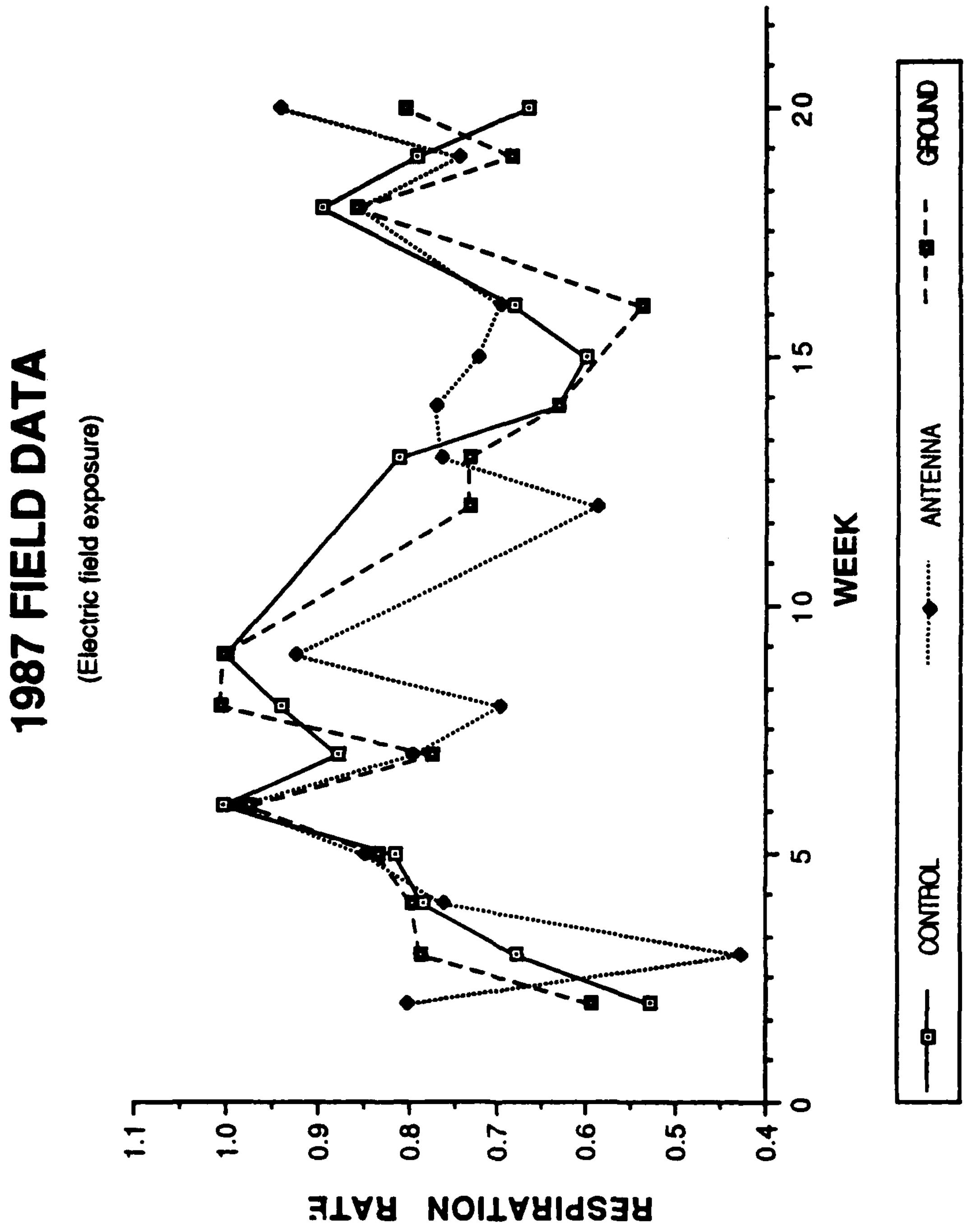
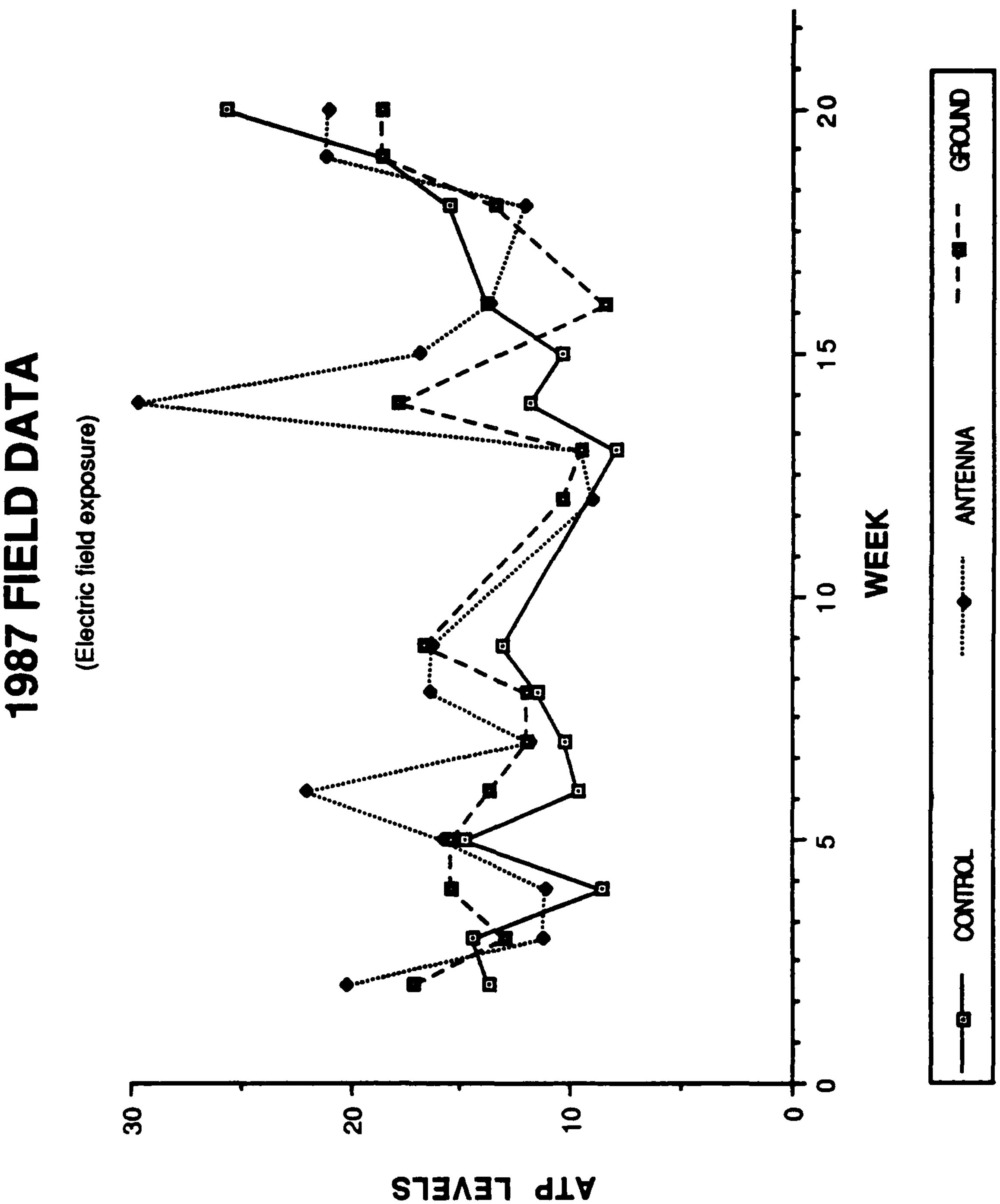

1987 FIELD DATA
(Electric field exposure)
RESPIRATION RATE
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0
5
10
15
20
WEEK
CONTROL
ANTENNA
GROUND

Figure 4



1987 FIELD DATA
(Electric field exposure)
ATP LEVELS
0
10
20
30
WEEK
0
5
10
15
20
CONTROL
ANTENNA
GROUND

Figure 5

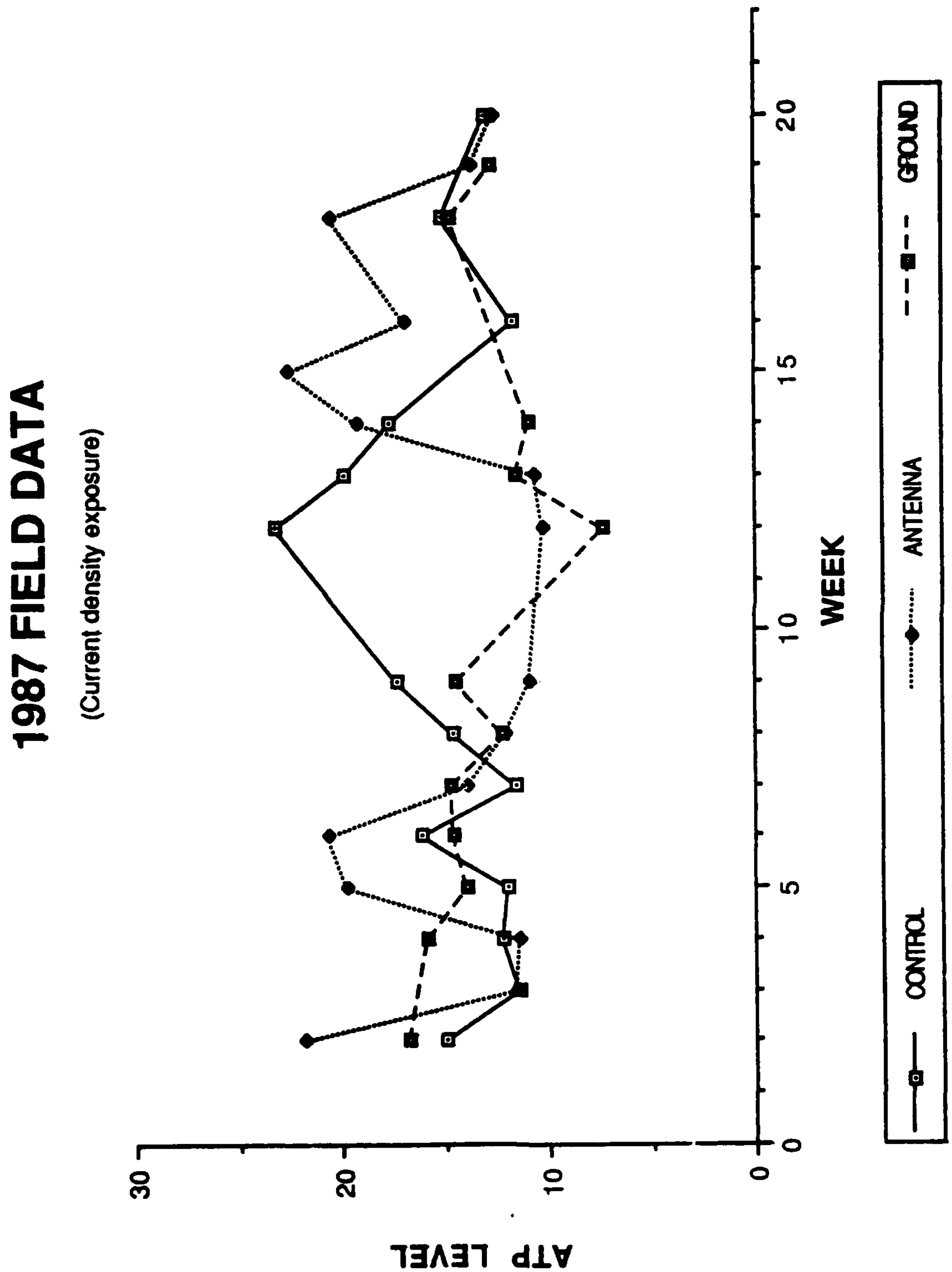

1987 FIELD DATA
(Current density exposure)
ATP LEVEL
30
20
10
0
WEEK
0
5
10
15
20
CONTROL
ANTENNA
GROUND

Figure 6

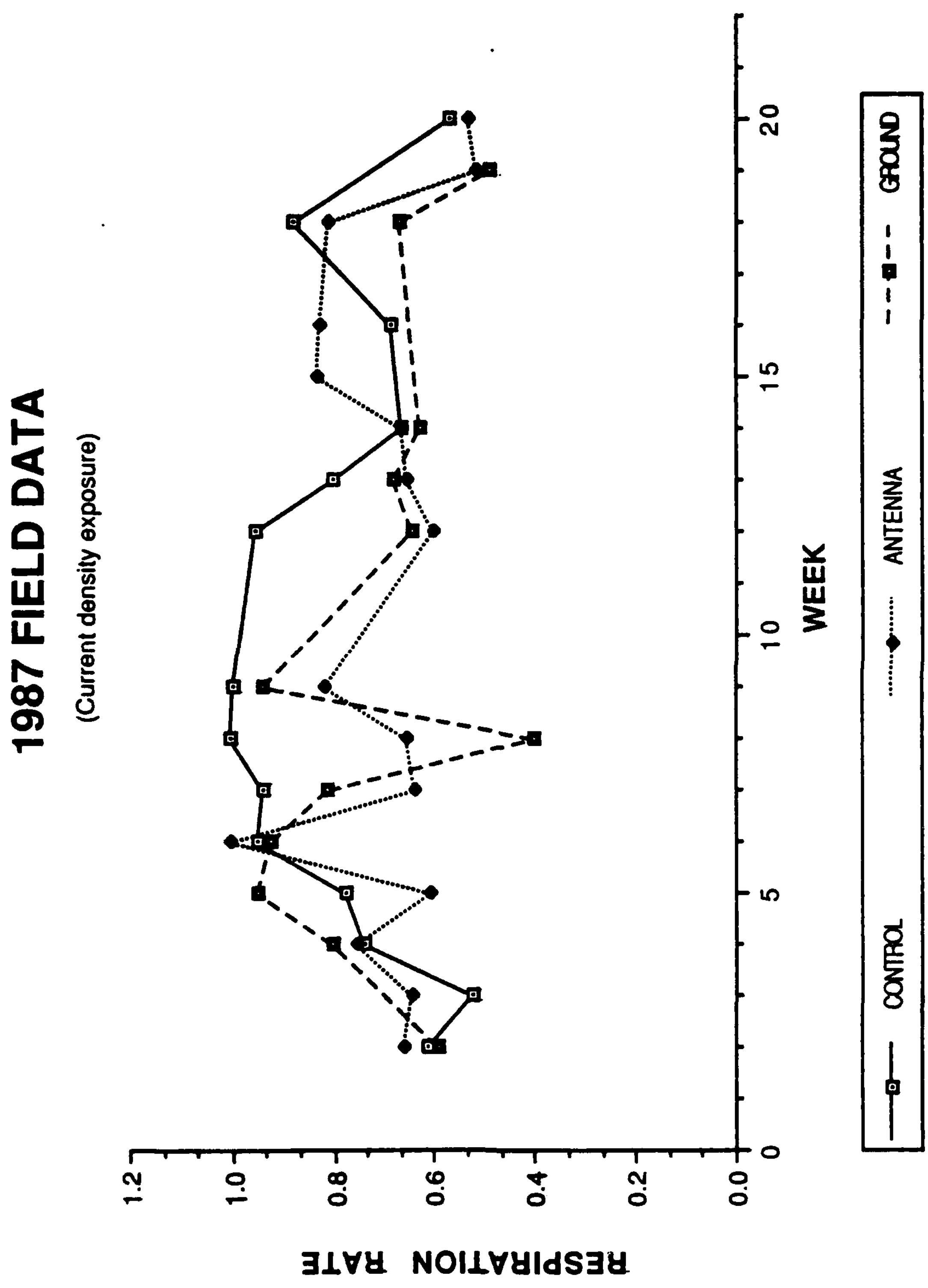

1987 FIELD DATA
(Current density exposure)
RESPIRATION RATE
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
WEEK
CONTROL
ANTENNA
GROUND

Figure 7

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Marron, M. T., Goodman, E. M., Greenebaum, B., and Tipnis, P. (1986) Effects of sinusoidal 60-Hz electric and magnetic fields on ATP and oxygen levels in the slime mold Physarum polycephalum. Bioelectromagnetics. 7:307-314.

APPENDIX A

DIRECT FIELD MEASUREMENTS AT THE W.T.F

V_{OC} = open circuit voltage

V_{C1} = voltage across test cell

V_R = voltage across 100 ohm resistor

a = electric field exposure sites

b = current density sites

E = earth's electric field measured at each site

-- field either not measured or too low to measure

** antenna known to be off at time of measurement

+ measurement taken, but inconsistent and probably incorrect

APPENDIX A

TABLE 1. (C-SITE)
(all measurements in millivolts)

	V_{OC}				V_{CL}			V_R		
DATE	E	1[a]	2[a]	3b	1	2	3	1	2	3
5/23/87	--	--	--	--	--	--	--	--	--	--
6/1/87	--	--	--	--	.19	2.2	.02	--	--	1.5
6/1/87	1.10	3.14	2.50	1.30	.17	.17	--	.30	.30	.97
6/8/87	--	--	--	--	.18	.18	--	1.9	.69	1.2
6/8/87	1.05	--	2.6	1.4	.16	.16	--	--	--	1.24
6/15/87	--	--	--	--	10.2	.12	--	.01	.50	1.20
6/15/87	1.08	3.0	2.7	1.36	.17	.17	--	--	--	1.21
6/22/87	--	--	--	--	.18	.18	--	.69	--	1.10
6/22/87	1.30	2.8	2.6	1.3	.20	--	--	1.6	--	1.1
6/29/87	--	--	--	--	.26	.19	--	1.4	--	1.36
6/29/87	1.18	3.0	2.7	1.4	.18	.17	--	1.6	--	1.38
7/6/87	--	--	--	--	.12	--	--	.75		1.19
7/6/87	--	--	--	1.1	--	--	--	--	--	1.21
7/13/87	--	--	--	--	--	--	--	--	--	--
7/13/87	1.10	3.2	2.9	1.49	.17	.17	.01	--	--	1.27
7/20/87	--	--	--	--	--	--	--	--	--	--
7/20/87	1.15	3.1	2.8	1.19	.18	.18	.10	--	.01	1.10
7/27/87	--	--	--	--	.16	.07	.01	--	.01	1.13
7/27/87	1.10	3.1	3.0	1.3	.17	.07	--	.01	--	.94
8/3/87	--	--	--	--	.15	.13	.02	--	--	.75
8/3/87	1.17	3.0	2.9	1.3	.18	.18	--	--	--	.87
8/10/87	--	--	--	--	.02	.11	.01	--	--	1.08
8/10/87	1.20	3.0	2.8	1.4	.09	.10	.02	--	--	.77
8/17/87	--	--	--	--	.20	.24	.02	--	--	1.3
8/17/87	1.20	3.1	2.8	1.5	.16	.10	--	--	--	1.3
8/24/87	**	**	**	**	**	**	**	**	**	**
8/24/87	**	**	**	**	**	**	**	**	**	**
8/30/87	--	--	--	--	.50	.21	--	--	--	--

APPENDIX A

TABLE 1. (C-SITE)

	V_{OC}				V_{CL}			V_R		
DATE	E	1[a]	2[a]	3[b]	1	2	3	1	2	3
8/30/87	1.00	2.9	2.8	1.3	.10	.20	--	--	--	1.30
9/6/87	--	--	--	--	.21	.22	.01	--	--	1.36
9/6/87	1.10	3.08	2.6	1.38	.17	.17	--	--	--	1.35
9/12/87	--	--	--	--	2.5^+	2.5	.01	--	--	1.30
9/12/87	1.20	3.1	2.78	1.30	.19	.19	--	--	--	1.27
9/19/87	--	--	--	--	.23	.23	.01	--	--	1.28
9/19/87	1.16	3.14	2.70	1.40	.25	.25	.01	--	--	1.30
9/26/87	--	--	--	--	.25	.30	.01	--	--	1.32
9/26/87	1.10	3.00	2.50	1.36	.17	.17	--	--	--	1.25
10/3/87	--	--	--	--	--	--	--	--	--	
10/3/87	1.10	3.13	2.70	1.36	.17	.17	--	--	--	1.33
10/10/87	--	--	--	--	1.3^+	.02	.01	--	--	1.33
10/17/87	1.60	3.25	2.60	1.34	.25	.25	.01	--	--	1.37

APPENDIX A

TABLE 2. (C-SITE)

Calculated Field Exposures at W.T.F.

	Current Density (mA/m^2)			Electric Field (mV/m)		
DATE	1[a]	2[a]	3[b]	1	2	3
6/1/87	--	--	.0022	1.23	14.2+	.13
6/1/87	3.33	3.33	.0033	1.10	1.10	--
6/8/87	21.1	7.67	.0028	1.16	1.16	--
6/8/87	--	--	.0027	1.03	1.03	--
6/15/87	.056	5.56	.0027	67.7+	.74	--
6/15/87	--	--	.0027	1.16	1.16	--
6/22/87	7.67	--	.0024	1.29	--	--
6/22/87	17.7	--	.0024	1.29	--	--
6/29/87	15.5	--	.0030	1.67	1.23	--
6/29/87	17.8	--	.0030	1.16	1.10	--
7/6/87	8.3	--	.0027	.77	--	--
7/6/87	--	--	.0026	--	--	--
7/13/87	--	--	--	--	--	--
7/13/87	--	--	.0028	1.10	1.10	.06
7/20/87	--	--	--	--	--	--
7/20/87	--	.11	.0024	1.16	1.16	.65
7/27/87	--	.11	.0025	1.03	0.45	.065
7/27/87	.11	--	.0021	1.10	0.45	--
8/3/87	--	--	.0017	.97	.84	.13
8/3/87	--	--	.0019	1.16	1.16	--
8/10/87	--	--	.0024	0.003	0.71	0.06
8/10/87	--	--	.0017	0.58	0.65	0.13
8/17/87	--	--	.0029	1.29	1.55	0.13

APPENDIX A

TABLE 2. (C-SITE)

Calculated Field Exposures at W.T.F.

	Current Density (mA/m^2)			Electric Field (mV/m)		
DATE	1[a]	2[a]	3[b]	1	2	3
8/17/87	--	--	.0029	1.03	.65	--
8/24/87	**	**	**	**	**	**
8/24/87	**	**	**	**	**	**
8/30/87	--	--	--	3.22+	1.35	
8/30/87	--	--	.0029	.65	1.29	--
9/6/87	--	--	.0030	1.35	1.42	.065
9/6/87	--	--	.0030	1.10	1.10	--
9/12/87	--	--	.0029	1.23	1.23	--
9/12/87	--	--	.0028	1.23	1.23	--
9/19/87	--	--	.0029	1.48	1.48	0.06
9/19/87	--	--	.0029	1.61	1.61	0.06
9/26/87	--	--	.0029	1.61	1.94	--
9/26/87	--	--	--	1.10	1.10	--
10/3/87	--	--	.0030	--	--	--
10/3/87	--	--	.0030	1.10	1.10	--
10/10/87	--	--	.0030	8.39+	.13	0.06
10/10/87	--	--	.0030	1.61	1.61	0.06

APPENDIX A

TABLE 3. (A-SITE)
(all measurements in millivolts)

	V_{OC}				V_{CL}			V_R		
DATE	E	1[a]	2[a]	3[b]	1	2	3	1	2	3
5/23/87	--	--	--	--	--	--	--	--	--	--
6/1/87	--	--	--	--	46	--	.20	6.8	--	180
6/1/87	200	460	500	182	31	28	.12	6.7	6.8	180
6/8/87	--	--	--	--	34	21	.20	4.5	3.6	190
6/8/87	200	460	510	190	30	30	.31	4.7	11	188
6/15/87	--	--	--	--	31	31	.18	5.4	6.2	189
6/15/87	200	450	510	190	30	32	.22	4.2	5.9	188
6/22/87	--	--	--	--	29	10	.02	3.8	4.6	191
6/22/87	210	460	520	197	32	32	.17	3.9	8.3	193
6/29/87	--	--	--	--	60	60	.22	7.6	10	196
6/29/87	210	460	530	198	30	30	.21	5.2	5.7	196
7/6/87	--	--	--	--	31	26	.02	4.9	5.0	188
7/6/87	195	470	510	190	30	30	.19	5.6	5.6	188
7/13/87	--	--	--	--	50	40	.22	4.7	6.5	194
7/13/87	206	460	520	196	32	32	.21	5.0	3.0	195
7/20/87	--	--	--	--	29	29	.21	4.5	3.4	191
7/20/87	210	460	510	190	33	33	.15	--	5.4	189
7/27/87	--	--	--	--	30	25	.18	1.4	4.0	187
7/27/87	200	460	490	190	31	31	.15	5.4	5.4	186
8/3/87	--	--	--	--	48	46	.16	7.5	8.3	180
8/3/87	200	460	500	180	31	31	.18	4.4	5.5	162
8/10/87	--	--	--	--	20	19	.15	4.0	8.0	180
8/10/87	210	470	510	200	--	--	.18	1.9	--	190
8/17/87	--	--	--	--	--	--	.03	--	--	--
8/17/87	210	470	520	190	32	27	.19	--	5.5	190
8/24/87	**	**	**	**	**	**	**	**	**	**
8/24/87	**	**	**	**	**	**	**	**	**	**
8/30/87	--	--	--	--	19	28	--	2.6	4.2	185

APPENDIX A

TABLE 3. (A-SITE)

	V_{OC}				V_{CL}			V_R		
DATE	E	1[a]	2[a]	3[b]	1	2	3	1	2	3
8/30/87	200	480	530	200	25	24	.20	4.0	4.3	195
9/6/87	--	--	--	--	33	34	.28	4.8	5.2	193
9/6/87	220	480	540	200	29	32	.20	5.0	5.1	196
9/12/87	--	--	--	--	40	56	.36	5.2	6.5	193
9/12/87	210	480	530	199	32	40	.37	4.8	7.0	192
9/19/87	--	--	--	--	46	48	.42	6.7	7.5	196
9/19/87	210	480	530	200	33	33	.47	5.8	5.3	196
9/26/87	--	--	--	--	36	30	.43	5.7	4.6	193
9/26/87	200	480	520	197	31	31	.23	5.2	4.8	195
10/3/87	--	--	--	--	40	40	.38	4.8	5.0	195
10/3/87	207	490	530	190	30	30	.23	3.9	5.2	196
10/10/87	--	--	--	--	40	39	.35	3.3	4.7	200
10/17/87	210	500	530	200	32	32	.27	2.4	4.4	200

APPENDIX A

TABLE 4. (A-SITE)

Calculated Field Exposures at W.T.F.

	Current Density (mA/m²)			Electric Field (mV/m)		
DATE	1[a]	2[a]	3[b]	1	2	3
6/1/87	75.56	--	.4000	296.8	--	1.29
6/1/87 6/8/87	74.44 50.00	75.56 40.00	.4000 .4178	200.0 219.4	180.6 135.5	0.77 1.29
6/8/87 6/15/87	52.20 60.00	122.2 68.89	.4222 .4200	193.5 200.0	193.5 200.0	2.00 1.16
6/15/87 6/22/87	46.67 42.22	65.56 51.12	.4178 .4244	193.5 187.1	206.5 64.5	1.42 .129
6/22/87 6/29/87	43.32 84.44	92.22 111.0	.4288 .4356	206.5 387.1	206.5 387.1	1.10 1.42
6/29/87 7/6/87	57.78 54.44	63.33 55.56	.4356 .4178	193.5 200.0	193.5 167.7	1.35 .129
7/6/87 7/13/87	62.22 52.22	62.22 72.22	.4178 .4311	193.5 322.6	193.5 258.1	1.23 1.42
7/13/87 7/20/87	55.56 50.00	33.33 37.78	.4333 .4244	206.5 187.1	206.5 187.1	1.35 1.35
7/20/87 7/27/87	-- 15.56	60.00 44.44	.4200 .4156	212.9 193.5	212.9 161.3	0.97 1.16
7/27/87 8/3/87	60.00 83.33	60.00 92.22	.4133 .4000	200.0 309.7	200.0 296.8	0.97 1.03
8/3/87 8/10/87	48.89 44.44	61.11 88.89	.3600 .4000	200.0 129.0	200.0 122.6	1.16 0.97
8/10/87 8/17/87	21.11 --	-- --	.4222 --	-- --	-- --	1.16
8/17/87 8/24/87	-- **	-- **	-- **	-- **	-- **	-- **

APPENDIX A

TABLE 4. (A-SITE)

Calculated Field Exposures at W.T.F.

	Current Density (mA/m^2)			Electric Field (mV/m)		
DATE	1[a]	2[a]	3[b]	1	2	3
8/24/87	**	**	**	**	**	**
8/30/87	28.89	46.67	.4111	122.6	180.7	--
8/30/87	44.44	47.78	.4333	161.3	154.8	1.29
9/6/87	53.33	57.78	.4289	212.9	219.4	1.81
9/6/87	55.56	56.67	.4356	187.1	206.4	1.29
9/12/87	57.78	72.22	.4289	258.1	361.3	2.32
9/12/87	53.33	77.78	.4267	206.4	258.1	2.39
9/19/87	74.44	83.33	.4356	296.8	309.7	2.71
9/19/87	64.44	58.89	.4356	212.9	212.9	3.03
9/26/87	63.33	51.11	.4289	232.3	193.5	2.77
9/26/87	57.78	53.33	.4333	200.0	200.0	1.48
10/3/87	53.33	55.56	.4333	258.1	258.1	2.45
10/3/87	43.33	57.78	.4356	193.5	193.5	1.48
10/10/87	36.67	52.22	.4444	258.1	251.6	2.26
10/17/87	26.67	48.89	.4444	206.4	206.4	1.74

APPENDIX A

TABLE 5. (G-SITE)
(all measurements in millivolts)

	V_{OC}				V_{CL}			V_R		
DATE	E	1[a]	2[a]	3[b]	1	2	3	1	2	3
5/23/87	--	--	--	--	--	--	--	--	--	--
6/1/87	--	--	--	--	100	140	1.53	17	24	340
6/1/87	480	1790	1560	710	74	74	.66	15	16	370
6/8/87	--	--	--	--	97	--	1.01	15	13	490
6/8/87	570	1840	1600	730	88	88	.99	15	14	550
6/15/87	--	--	--	--	94	94	.95	14	9	720
6/15/87	550	--	1610	740	85	85	.67	18	19	710
6/22/87	--	--	--	--	87	79	.92	14	13	500
6/22/87	600	1900	1640	750	93	93	--	16	11	500
6/29/87	--	--	--	--	120	160	1.03	17	25	690
6/29/87	520	1860	1700	720	80	80	.80	14	14	700
7/6/87	--	--	--	--	82	180	.80	12	13	660
7/6/87	650	1800	1700	690	100	100	.76	17	19	670
7/13/87	--	--	--	--	50	40	.22	4.7	6.5	194
7/13/87	206	460	520	196	32	32	.21	5	3	195
7/20/87	--	--	--	--	29	29	.21	4.5	3.4	191
7/20/87	660	1850	1620	710	100	100	.90	16	18	680
7/27/87	--	--	--	--	93	500	.38	14	12	137
7/27/87	680	1830	1620	680	80	105	.68	19	20	670
8/3/87	--	--	--	--	115	140	--	22	24	490
8/3/87	680	1840	1650	670	105	105	.90	20	19	560
8/10/87	--	--	--	--	90	90	.95	--	15	370
8/10/87	690	1800	1650	700	107	107	.91	7	19	590
8/17/87	--	--	--	--	--	--	--	--	--	--
8/17/87	550	1830	1600	640	86	84	.07	13	14	220
8/24/87	**	**	**	**	**	**	**	**	**	**
8/24/87	**	**	**	**	**	**	**	**	**	**
8/30/87	--	--	--	--	80	80	4.5	12	13	610

APPENDIX A

TABLE 5. (G-SITE)

	V_{OC}				V_{CL}			V_R		
DATE	**E**	**1[a]**	**2[a]**	**3[b]**	**1**	**2**	**3**	**1**	**2**	**3**
8/30/87	700	1780	1650	680	75	101	.90	13	17	640
9/6/87	--	--	--	--	76	110	--	89	--	600
9/6/87	650	1760	1630	660	70	100	--	13	18	440
9/12/87	--	--	--	--	80	120	--	10	17	540
9/12/87	640	1800	1660	630	70	99	1.1	11	3	550
9/19/87	--	--	--	--	98	140	.90	14	10	540
9/19/87	600	1730	1620	600	90	90	3.3	14	13	540
9/26/87	--	--	--	--	100	93	5.8	15	12	--
9/26/87	610	1760	1600	610	127	70	1.0	4.2	5.4	570
10/3/87	--	--	--	--	100	92	1.0	5.1	4.3	440
10/3/87	640	1740	1640	600	890	100	20	3.4	16	500
10/10/87	--	--	--	--	50	120	21	6.6	14	500
10/17/87	660	1750	1700	600	100	100	.78	10	16	510

APPENDIX A

TABLE 6. (G-SITE)

Calculated Field Exposures at W.T.F.

	Current Density (mA/m^2)			Electric Field (mV/m)		
DATE	1[a]	2[a]	3[b]	1	2	3
6/1/87	186.9	266.7	.7556	645.2	903.2	9.87
6/1/87	166.7	177.8	.8222	477.4	477.4	4.23
6/8/87	163.3	144.4	1.089	625.8	--	6.52
6/8/87	161.1	150.0	1.222	567.7	567.7	6.39
6/15/87	160.0	104.4	1.600	606.4	606.4	8.26
6/15/87	200.0	600.0	1.578	548.4	584.4	4.32
6/22/87	155.6	143.3	1.111	561.3	509.7	8.00
6/22/87	177.8	124.4	1.111	600.0	600.7	--
6/29/87	188.9	277.8	1.533	774.2	1032	6.65
6/29/87	155.6	155.6	1.556	516.1	516.1	5.16
7/6/87	133.8	138.9	1.467	529.0	1161	5.16
7/6/87	185.6	211.1	1.489	645.2	645.2	4.90
7/13/87	311.1	216.7	.4333	322.6	258.1	1.42
7/13/87	55.56	33.33	.4333	206.5	206.5	1.35
7/20/87	50.00	37.78	.4244	187.0	187.0	1.35
7/20/87	177.8	200.0	1.511	645.2	645.2	5.81
7/27/87	155.6	133.3	.3044	600.0	3225[+]	2.45
7/27/87	211.1	222.2	1.489	516.1	677.4	4.39
8/3/87	244.4	266.7	1.089	1000	1217	--
8/3/87	222.2	211.1	1.244	677.4	677.4	5.81
8/10/87	--	166.7	.8222	580.6	580.6	6.13
8/10/87	77.78	211.1	1.311	690.3	690.3	5.87
8/17/87	--	--	--	--	--	--
8/17/87	144.4	155.6	--	554.8	541.9	0.45
8/24/87	**	**	**	**	**	**

APPENDIX A

TABLE 6. (G-SITE)

Calculated Field Exposures at W.T.F.

	Current Density (mA/m²)			Electric Field (mV/m)		
DATE	1[a]	2[a]	3[b]	1	2	3
8/24/87	**	**	**	**	**	**
8/30/87	133.3	144.4	1.356	516.1	516.1	5.81
8/30/87	144.4	188.9	1.422	483.9	651.6	5.81
9/6/87	989+	--	1.333	490.3	709.7	--
9/6/87	144.4	200.0	.9778	451.6	645.2	--
9/12/87	111.1	188.9	1.200	516.1	774.2	--
9/12/87	122.2	33.39	1.222	451.6	638.0	--
9/19/87	155.6	111.1	1.200	623.3	903.2	5.81
9/19/87	155.6	144.4	1.200	580.6	580.6	2.13
9/26/87	166.7	133.3	--	645.2	600.0	3.74-
9/26/87	46.67	60.08	1.111	819.3	451.6	6.45
10/3/87	56.67	47.78	.9778	645.2	593.5	6.45
10/3/87	37.78	177.8	1.111	574.0	645.2	12.9
10/10/87	73.33	155.6	1.111	322.6	774.2	13.5
10/10/87	111.1	177.8	1.133	645.2	645.2	5.03

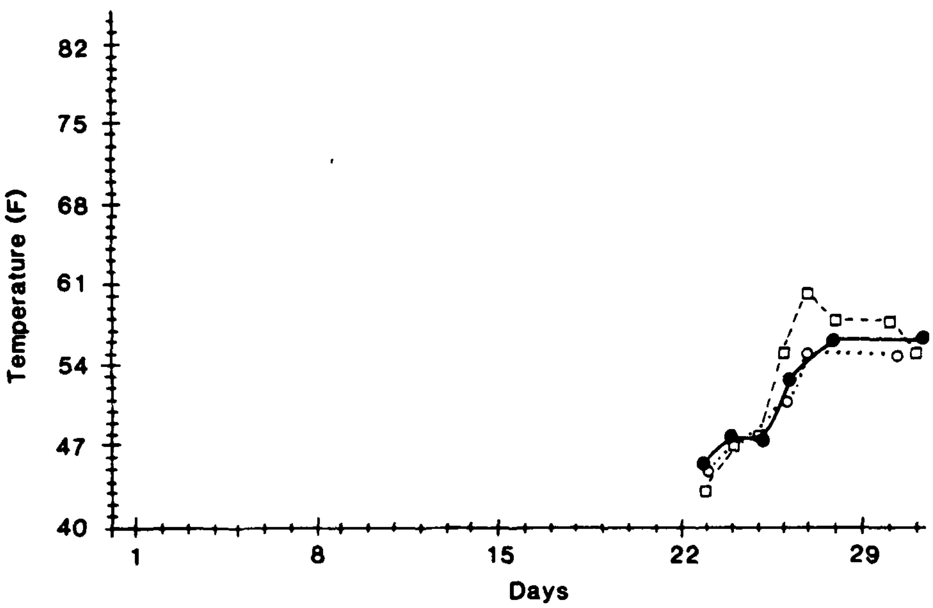
APPENDIX B

A DAILY TEMPERATURE SUMMARY AT THE CONTROL, ANTENNA, AND GROUND SITES

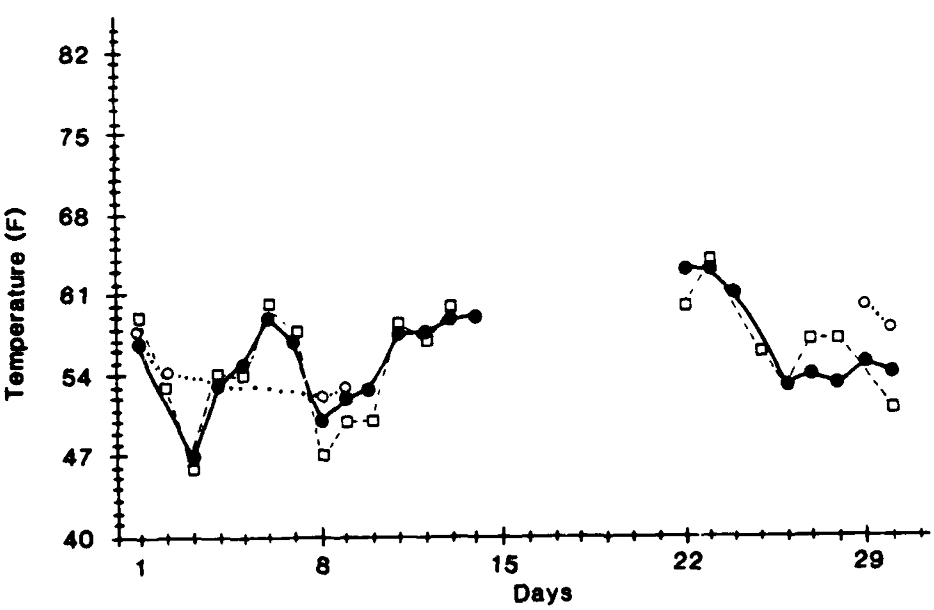
Control Site = +

Antenna Site = ○

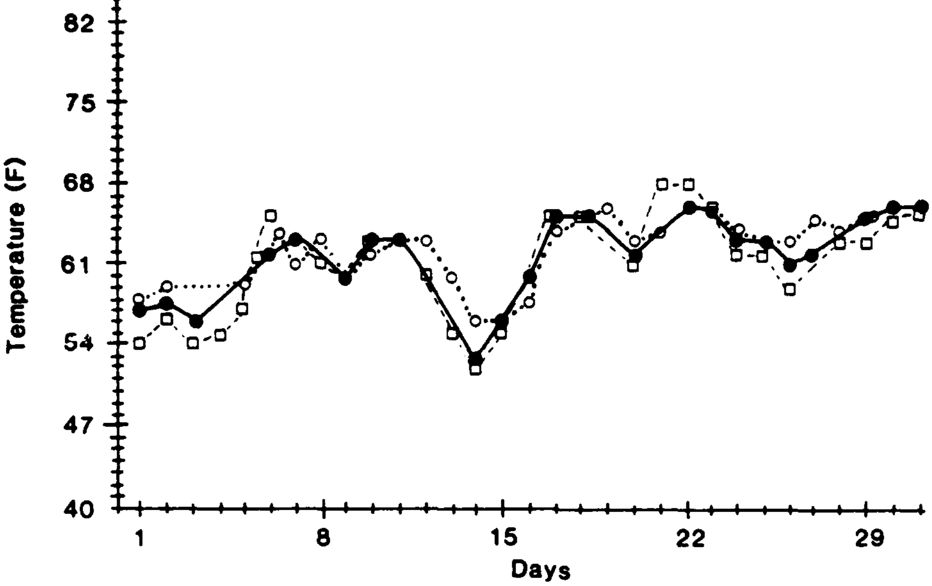
Ground Site = ■



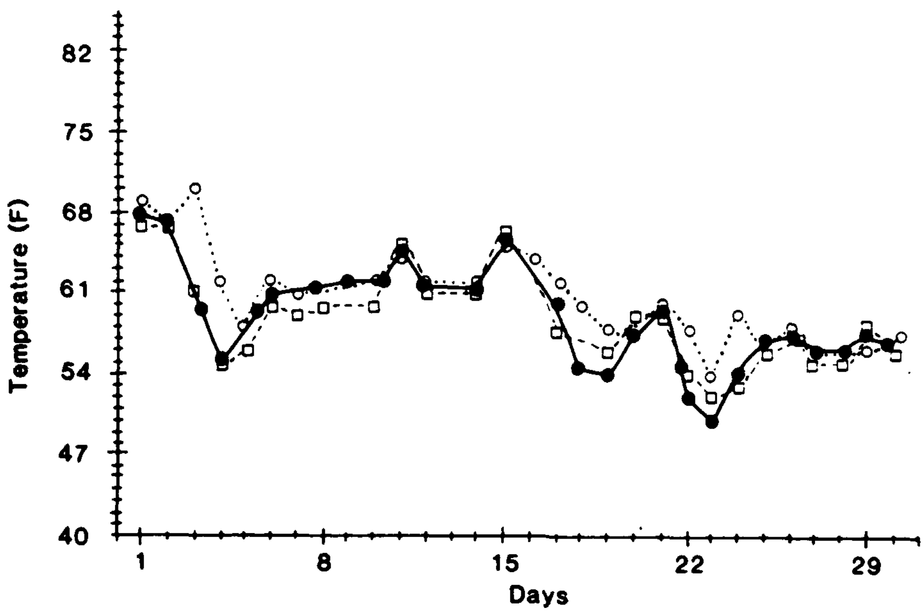
5/23/87 - 5/31/87



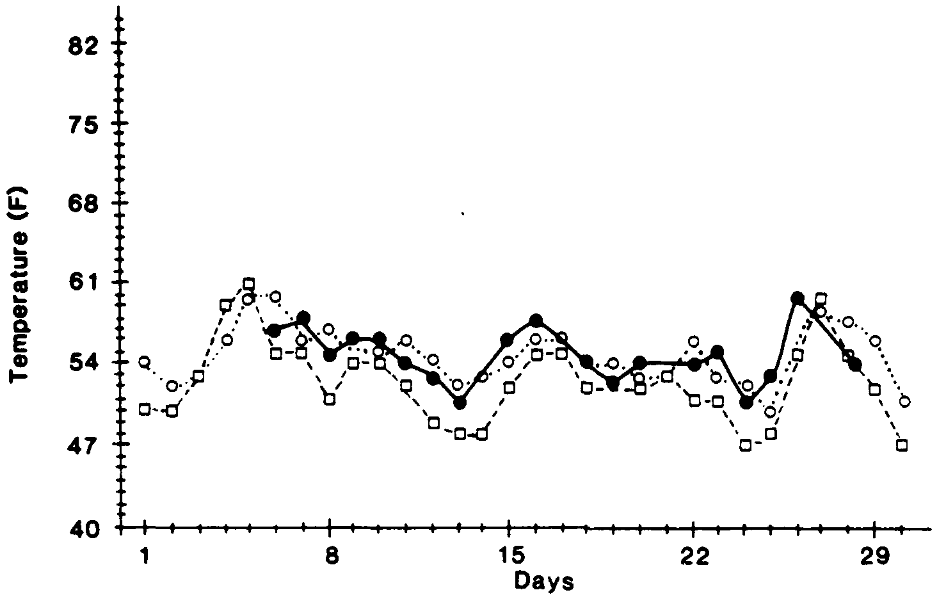
6/1/87 - 6/30/87



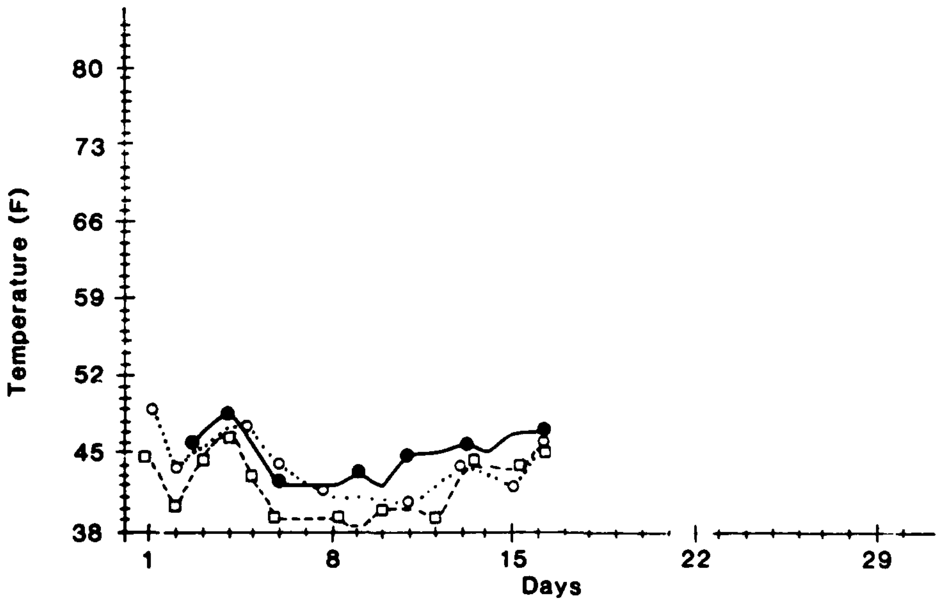
7/1/87 - 7/31/87



8/1/87 - 8/30/87



9/1/87 - 9/30/87



10/1/87 - 10/31/87

APPENDIX C

DATA FROM THE WISCONSIN TEST SITE

I.D. = date experiment was performed in the laboratory

Site = exposure site at WTF (Control = C; Antenna = A; Ground = G)

Days = number of days macroplasmodium was exposed in the field

Temp-Lo = average low daily temperature

Temp-Hi = average high daily temperature

J = calculated weekly current density at an exposure site

E = calculated electric field at an exposure site

Hrs = number of hours the plasmodium was out of the field prior to analyzing its QO_2 or ATP content

QO_2 = ul O_2 consumed/mg protein/min

ATP = nM ATP/mg protein

-- = data not acquired

W.T.F.-FIELD DATA

I.D.	Site	Days	Temp-Lo	Temp-Hi	J	E	Hrs	QO_2	ATP	
6/5/87	C-2	10	41474852555555	47495155565757	--	1.23	60	.662.641.632	--	--
	C-3				.0022	0.13		.783.755.720	--	--
	A-1		43454748525554	48484852555656	75.56	296.8		.857.913.898	--	--
	A-3				.4000	1.29		.702.727.712	--	--
	G-2		40444749565152	50515161666262	266.7	903.2		.589.589.606	--	--
	G-3				.7556	9.87		.626.657.610	--	--
6/11/87	C-2	17	54494550535753	60575356586261	7.67	1.16	40	.553.512.522	12.05,15.29	
	C-3				.0028	--		.625.607.601	14.52,15.36	
	A-1		5547----------	5956---------	50.00	219.4		.843.710.853	20.36,20.06	
	A-3				.4178	1.29		.666.670.645	23.01,20.81	
	G-2		53464045475052	60605263627065	144.4	--		.589.589.606	17.44,16.94	
	G-3				1.089	6.52		.613.591.578	13.52,20.08	
6/12/87	C-2						64	.858.748.831	11.75,11.81	
	C-3							.804.840.721	15.81,25.61	
	A-1							.685.738.797	24.57,16.00	
	A-3							.636.653.643	14.29,17.62	
	G-2							.821.792.809	11.88,17.01	
	G-3							.739.729.831	18.49,13.15	
6/15/87	C-2						136	.662.671.656	17.86,20.88	
	C-3							.679.687.693	14.05,22.37	
	A-1							.634.637.703	20.86,19.88	
	A-3							.749.676.823	21.57,17.80	
	G-2							.697.666.737	13.27,12.89	
	G-3							.766.678.718	15.64,18.38	

W.T.F.-FIELD DATA (continued)

I.D.	Site	Days	Temp-Lo	Temp-Hi	OD	E	Hrs	QO_2	ATP
6/18/87	C-1	24	45475054555754	51545561606464	.056	.74	40	.714.646.675	10.01,18.83
	C-3				.0027	--		.505.553.515	12.28,10.49
	A-1		4848	5553	46.67	193.5		.435.434.418	10.66,11.86
	A-3				.4178	1.42		.659.631.642	10.97,11.97
	G-2		41404850505448	55585566647271	600.0	584.4		.774.805.783	11.39,14.47
	G-3				1.578	4.32		-- -- --	-- --
6/22/87	C-1						136	.910.871.874	13.22,18.39
	C-3							.748.727.768	17.61,23.91
	A-1							1.026.877	15.57,20.14
	A-3							.689.670.692	19.74,15.92
	G-2							.721.851.794	21.80,23.1
	G-3							-- -- --	-- --
6/25/87	C-1	31	-------------	-------------	7.67	1.29	40	.776.767.807	7.9,10.3
	C-3				.0024	--		.843.640.731	14.44,9.93
	A-1		-------------	-------------	42.22	187.1		.801.683.798	10.71,11.60
	A-3				.4244	0.13		.850.726.692	10.61,12.29
	G-1		-------------	-------------	155.6	561.3		.798.811.777	13.73,17.02
	G-3				1.111	8.00		.898.723.789	15.83,15.89
6/29/87	C-1						136	.802.832.757	17.02,15.45
	C-3							1.06.980.939	20.73,16.86
	A-1							.957.972.897	14.54,15.75
	A-3							.8981.17.968	12.01,15.74
	G-1							.837.728.821	18.42,17.05
	G-3							1.12.976.882	20.26,20.78

W.T.F.-FIELD DATA (continued)

I.D.	Site	Days	Temp-Lo	Temp-Hi	J	E	Hrs	QO_2	ATP
7/2/87	C-2	38	59595853505156	65686561565761	--	1.68	40	.764.842.833	15.58,13.97
	C-3				.0030	--		.788.777.763	11.84,12.03
	A-2				111.0	387.1		.838.925.779	14.43,17.24
	A-3				.4356	1.42		.995.8151.11	12.86,26.69
	G-2		55565750464751	70736562565963	277.8	1032		.806.846.845	15.58,15.18
	G-3				1.533	6.65		.895.994.971	14.15,13.66
7/6/87	C-2						136	.875.887.894	12.35,10.73
	C-3							.927.871.869	13.62,16.34
	A-2							.868.881.865	25.56,18.26
	A-3							.87 1.05.984	14.47,16.90
	G-2							.973.951.898	15.43,11.20
	G-3							.907.983.863	12.84,10.23
7/9/87	C-1	45	52525656535659	57565859585960	8.3	.77	40	1.04 1.1 1.1	9.64,9.64
	C-3				.0027	--		.942.928.987	13.20,18.97
	A-1		58545356575456	61585860606060	54.44	200.0		1.1 1.03.959	20.18,23.95
	A-3				.4178	0.13		1.3 1.3 1.15	20.52,20.99
	G-1		47474954485154	57555759585859	133.8	529.0		1.0.924 1.04	14.65,12.86
	G-3				1.467	5.16		.916.922.935	15.47,13.72
7/13/87	C-1						136	.736.743.779	9.01,9.55
	C-3							.790.749.716	8.53,8.47
	A-1							-- -- --	-- ---
	A-3							.590.628.627	15.10,20.01
	G-1							.607.607	14.15,14.94
	G-3							.606.588.602	9.00,12.20

W.T.F.-FIELD DATA (continued)

I.D.	Site	Days	Temp-Lo	Temp-Hi	J	E	Hrs	QO_2	ATP
7/16/87	C-2	52	59596058616256	62696362646463	--	--	40	.935.840.857	9.89,10.58
	C-3				--	--		.980.935.904	11.58,11.60
	A-1		61606060606263	62696362646463	52.22	322.6		.748.774.865	9.69,14.08
	A-3				.4311	1.42		.616.641.659	11.65,16.00
	G-2		59595958596156	61696360656464	216.7	258.1		.764.633.919	12.38,11.65
	G-3				.4333	1.42		.828.849.763	12.22,17.24
7/20/87	C-2						136	.761.783.851	10.12,11.20
	C-3							.88 1.06.896	10.23,11.92
	A-1							-- -- --	-- --
	A-3							.910.915.892	10.35,11.63
	G-2							.857.881.891	11.95,13.73
	G-3							.856.934.891	11.09,21.97
7/23/87	C-1	59	52515558646061	58565862676768	--	--	40	.979.916.929	11.87,11.16
	C-3				--	--		1.3 1.1 1.04	13.81,15.39
	A-1		59545356606464	61585961676667	50.00	187.1		.997.96 1.05	14.97,17.75
	A-3				.4244	1.35		.99 1.0 .860	11.64,12.58
	G-1		46464954616356	59565863696769	50.00	187.0		1.2 1.0 1.13	8.06,15.92
	G-3				.4244	1.35		.99.97 1.04	11.76,12.63
7/27/87	C-1						136	.804.837.820	15.84,14.90
	C-3							.843.759.760	8.76,8.96
	A-1							.982.855.912	8.42,8.47
	A-3							.948.966.830	11.23,13.96
	G-1							.753.854.780	9.94,12.41
	G-3							.931.874.849	12.16,15.66

W.T.F.-FIELD DATA (continued)

I.D.	Site	Days	Temp-Lo	Temp-Hi	J	E	Hrs	QO_2	ATP
7/30/87	C-1	66	61636563606157	63666868656564	.110	1.10	40	1.0 1.1 1.1	12.30,13.90
	C-3				.0021	--		1.1 1.1 .996	12.98,21.53
	A-1		62626565646061	62686868676664	15.56	193.5		.940.891	13.59,18.99
	A-3				.4156	1.16		.859.779	10.19,11.67
	G-1		61616363565653	62898169666664	155.6	600.0		1.2 1.2 1.2	12.68,20.59
	G-3				.3044	2.45		.938.908.977	13.80,15.00
8/3/87	C-1						136	.93 1.06.950	12.73,17.35
	C-3							1.0 1.1 1.09	12.29,23.99
	A-1							.781.860.951	13.23,14.25
	A-3							1.3 1.34 1.3	10.90,15.21
	G-1							.993.991.924	9.56,10.91
	G-3							.94 1.0 1.05	15.10,18.83
8/17/87	C-1	73	61626465656665	63656768647069	--	0.58	136	.389.428.649	12.25,10.39
	C-3				.0017	0.13		.833.771.810	16.61,13.49
	A-2		63616262646766	66666768687069	44.44	1.29		.779.754.740	10.39,17.11
	A-3				.4000	1.03		.737.720.748	15.14,14.17
	G-1		59616060636464	64646668686969	--	580.6		1.02.937.989	13.97,13.44
	G-3				1.089	--		.722.794.698	15.15,15.13
8/20/87	C-2	87	59626060616360	64656264646866	--	1.03	40	-- -- --	-- --
	C-3				.0029	--		.945.935.998	18.44,28.32
	A-2		60606160606462	64756364646866	155.6	541.9		.561.553.648	7.44,10.68
	A-3				--	1.16		.667.536	8.51,11.84
	G-1		58585957586359	64736368637168	--	--		.724.718.758	9.69,11.23
	G-3				--	--		.619.692.625	6.45,8.17

W.T.F.-FIELD DATA (continued)

I.D.	Site	Days	Temp-Lo	Temp-Hi	J	E	Hrs	QO_2	ATP
8/25/87	C-1						160	.639.624.642	10.03,11.91
	C-2							.539.579.540	10.60,10.09
	A-2							.626.620.648	12.34,13.61
	A-3							.599.569.588	13.44,12.69
	G-2							.599.560.586	13.30,17.92
	G-3							-- -- --	-- ---
8/28/87	C-2	94	55504950534642	63605862635753	--	--	64	.757.847.829	9.80,6.20
	C-3				--	--		.772.796.845	16.45,23.25
	A-2		59585452575652	64626063646156	--	--		.732.781.780	8.04,11.00
	A-3				--	--		.649.669.650	10.62,10.69
	G-2		57545458555148	59595861635754	--	--		.736.768.697	7.71,11.28
	G-3				--	--		.680.686.675	9.91,13.20
9/1/87	C-2	100	535656555457	565758585859	--	1.35	16	.650.612.636	11.75,11.99
	C-3				--	--		.646.697.659	17.20,18.22
	A-1		575356565553	615859585959	28.89	122.6		.757.739.816	31.21,28.20
	A-3				.4111	--		.661.657.675	20.74,17.71
	G-2		495055504750	575759575962	144.4	516.1		.610.621.664	16.79,19.04
	G-3				1.356	5.81		.645.640.604	10.35,11.48
9/3/87	C-2						64	.543.591.539	12.62,17.60
	C-3							.755.749.728	17.75,17.81
	A-1							.605.667.795	13.14,13.64
	A-3							.770.781.769	14.55,15.27
	G-1							.658.679.650	13.73,14.46
	G-3							.596.724.604	12.37,15.39

W.T.F.-FIELD DATA (continued)

I.D.	Site	Days	Temp-Lo	Temp-Hi	J	E	Hrs	QO_2	ATP
9/4/87	C-2						88	.572.603.639	10.50,13.59
	C-3							.708.696.819	14.56,20.31
	A-1							.737.716.666	16.29,14.37
	A-3							.753.688.782	13.05,16.95
	G-1							.665.646.747	11.92,11.30
	G-3							.642.591.564	15.12,14.90
9/10/87	C-1	107	-------------	-------------	--	1.35	64	.610.591.600	9.82,11.01
	C-3				.0029	--		-- -- --	-- --
	A-2		56525250505458-	58555654556062	57.78	219.4		.706.698.762	13.08,20.73
	A-3				.4289	1.81		.721.906.871	24.31,21.06
	G-1		55464343495357	57545655566365	--	490.3		-- -- --	-- --
	G-3				1.333	--		-- -- --	-- --
9/11/87	C-1						88	.807.807.765	10.66,13.78
	C-2							.423.424.434	-- --
	A-2							.646.635.645	12.19,15.38
	A-3							.707.796.724	11.96,15.26
	G-2							-- -- --	-- --
	G-3							.562.581.604	12.89,14.00
9/15/87	C-1	113	555753555553	625957585756	--	1.23	40	.709.648.694	12.76,15.00
	C-3				.0029	--		.632.697.731	10.16,13.03
	A-2		585356505455	625858565656	72.22	361.3		.689.676.728	11.85,15.57
	A-3				.4289	2.32		.779.815.890	15.09,18.82
	G-1		464945475348	605852595655	111.1	516.1		.584.494.538	7.85,9.12
	G-3				1.200	--		-- -- --	-- --

W.T.F.-FIELD DATA (continued)

I.D.	Site	Days	Temp-Lo	Temp-Hi	J	E	Hrs	QO_2	ATP
9/16/87	C-1						64	.655.685.746	12.69,10.46
	C-3							.603.613.635	13.59,13.89
	A-2							.677.619.712	10.72,14.73
	A-3							.737.779.735	13.13,15.46
	G-1							.643.656.635	10.73,14.20
	G-3							.600.643	11.56,17.78
9/23/87	C-1	120	50495055575552	55535558595855	--	1.48	64	.636.563.633	12.43,11.76
	C-3				.0029	0.06		.626.745.631	10.12,15.70
	A-1		52504950525554	55545456585654	74.44	296.8		.637.660.655	22.50,19.40
	A-3				.4356	2.71		.635.740.682	17.13,20.49
	G-1		48404145515350	51525455575753	155.6	632.3		.559.533.790	11.74,16.31
	G-3				1.200	5.81		-- -- --	-- --
9/24/87	C-1						88	.893.928.842	13.46,14.65
	C-3							.767.916.893	11.91,14.61
	A-1							-- -- --	-- --
	A-3							.955.957.979	10.47,14.92
	G-1							.908.888.891	10.51,12.84
	G-3							-- -- --	-- --
9/30/87	C-1	127	52535451514752	54545557595756	--	1.61	64	.904.912.869	13.25,17.93
	C-3				.0029	--		.840.811.996	14.15,15.90
	A-2		53525254505047	55545465565352	51.11	193.5		.864.830.875	10.56,13.69
	A-3				.4289	2.77		.847.740.852	19.33,21.71
	G-2		50505149454045	54535455575351	133.3	600.0		.891.786.895	12.68,14.27
	G-3				--	3.74		.655.680.681	13.71,15.58

W.T.F.-FIELD DATA (continued)

I.D.	Site	Days	Temp-Lo	Temp-Hi	J	E	Hrs	QO_2	ATP
10/1/87	C-1						88	.811.856.956	12.92,18.67
	C-3							.845.830.822	14.87,16.47
	A-2							.793.840.835	13.70,16.51
	A-3							.845.856.924	23.03,20.83
	G-2							.823.918.845	17.24,15.24
	G-3							.803.696.716	12.51,13.74
10/7/87	C-1	134	585650--------	636059--------	--	--	64	.857.765.759	16.04,21.09
	C-3				.0030	--		-- -- --	-- --
	A-1		55545754494743	60626058525246	53.33	258.1		.804.717.717	19.73,22.53
	A-3				.4333	2.45		.526.511.522	13.50,13.65
	G-2		53545345454040	60635857505043	47.78	593.5		.707.697.653	19.63,17.60
	G-3				.9778	6.45		.503.468.508	11.27,14.11
10/8/87	C-1						88	.702.823.870	17.95,15.32
	C-3							.716.558	24.00,30.65
	A-1							.796.867.882	14.25,15.24
	A-3							.787.704.867	13.01,13.32
	G-2							.755.763.726	13.04,18.59
	G-3							.624.569.576	9.77,11.70
10/13/87	C-1	141	42484441404140	52524844444345	--	8.39	40	.688.633.677	23.20,28.11
	C-2				--	0.13		.964.898.969	21.28,20.92
	C-3				.0030	0.06		.570.578.558	12.13,13.85
	A-1		44424543404039	47524844424342	36.67	258.1		.813.807.796	17.41,19.84
	A-3				.4444	2.26		.536.532.535	11.96,13.11
	G-3		40434138383837	50534640404139	1.111	13.5			

W.T.F.-FIELD DATA (continued)

I.D.	Site	Days	Temp-Lo	Temp-Hi	J	E	Hrs	QO_2	ATP
10/14/87	C-1						64	.788.812.760	18.17,22.13
	C-3							.683.776.710	15.34,17.41
	A-1							.724.710.694	13.30,13.48
	A-3							.641.610.644	12.02,12.77
	G-2							.862.739.738	14.69,18.84
	G-3							.702.713.771	11.42,16.98
10/22/87	C-1	148	40404243454645	43464747464849	--	1.61	88	.668.649.691	13.79,23.09
	C-3				.0030	0.06		.788.774.755	16.12,22.21
	A-1		40383940414244	42424446454248	26.67	206.4		.730.722.693	19.93,27.18
	A-3				.4444	1.74		.743.762.710	17.08,22.94
	G-2		36363436424243	44434448454546	177.8	645.2		.725.712.706	22.35,28.02
	G-3				1.133	5.03		.662.662.663	17.42,20.86
10/23/87	C-1						112	.693.752.795	15.46,19.29
	C-3							.870.813	16.93,20.77
	A-1							.715.731.784	15.14,20.43
	A-3							.831.782.733	-- --
	G-2							.809.736.714	13.78,19.93
	G-3							.624.633.673	18.18,14.35

APPENDIX D

U.W.-LABORATORY STUDIES

I.D. = date experiment was performed in the laboratory

Site = exposure conditions at UW-P (Control = C; E-1 = E-field; E-2 = current density)

Days = number of days macroplasmodia were exposed to an electromagnetic field

J = current density (constant at 10 mV/m)

E = electric field (constant at 800 mV/m)

Hrs = number of hours the plamodium was out of the field prior to analyzing its QO_2 or ATP content

QO_2 = μl O_2 consumed/mg protein/min

ATP = nM ATP/mg protein

U.W.-PARKSIDE-LABORATORY STUDIES

I.D.	Exposure Conditions	Days	Hrs.	QO_2	ATP
6/9/87	C-1	13	72	1.01,980.932	20.24,23.61
	E-1			.904.918.884	39.87
	E-2			.949.795.875	
6/15/87	C-1	20	48	.583.686	21.48,32.29
	E-1			.734.748.774	23.64,23.33
	E-2			.731.811.823	
6/22/87	C-1	27	48	.549.603.520	20.84,16.06
	E-1			.586.621.600	18.89,15.36
	E-2			.707.648.572	24.08,27.96
6/29/87	C-1	34	48	.937.877.811	7.78,10.61
	E-1			.81.04 1.03	15.53,21.66
	E-2			.804.765.863	9.94,16.74
7/6/87	C-1	41	48	.884.722.719	6.89,10.22
	E-1			.934.832.863	10.66,15.26
	E-2			.804.822.906	6.69,10.79
7/13/87	C-1	48	48	.665.602.662	
	E-1			.710.610.782	12.26,17.39
	E-2			.690.815.739	20.54,20.16
7/22/87	C-1	57	72	.729.745.736	12.56.10.55
	E-1			.784.758.839	9.82,10.96
	E-2			.934.925.901	19.77,17.19
7/27/87	C-1	62	48	1.03.92 1.01	
	E-1			.549.598.624	
	E-2			.535.516.530	

U.W.-PARKSIDE-LABORATORY STUDIES (Continued)

I.D.	Exposure Conditions	Days	Hrs	QO_2	ATP
8/3/87	C-1	69	48	1.2 1.5 1.2	10.22,6.90
	E-1			1.2 1.1 1.1	9.89,14.05
	E-2			1.2 1.1 1.14	11.89,10.14
8/17/87	C-1	83	48	.766.795.774	14.65,14.37
	E-1			.693.691.671	16.16,14.99
	E-2			.644.678.675	16.95,20.72
8/25/87	C-9	90	72	.538.540.547	17.13,22.82
	E-1				
	E-2				
9/1/87	C-9	99	96	.522.577.486	18.43,15.47
	E-1				
	E-2			.561.548.505	12.97,15.98
9/8/87	C-9	104	96	.390.391.434	
	E-1			.441.392.406	
	E-2			.214.230.205	
9/15/87	C-9	111	96	.695.756.741	12.69,17.45
	E-1			.712.709.753	15.58,19.76
	E-2			.722.750.847	13.53,16.06
9/23/87	C-9	120	72	.688.681.702	13.09,14.49
	E-1				
	E-2			.628.668.607	15.73,20.82
9/24/87	C-9				
	E-1		96	.643.646.620	15.66,16.01
	E-2				
9/30/87	C-9	129	72	.9371.09.890	17.12,22.08

U.W.-PARKSIDE-LABORATORY STUDIES (Continued)

I.D.	Exposure Conditions	Days	Hrs	QO_2	ATP
	E-1			1.17.914.957	13.27,17.64
	E-2			.956.794.996	13.24,17.93
10/7/87	C-9	134	72	.526.571.583	17.13,17.00
	E-1			.638.579.655	16.93,13.57
	E-2			.533.582.585	12.94,15.26
10/8/87	C-9		96	1.05.788.830	11.90,14.88
	E-1			.899.693.783	12.50
	E-2			.716.677.730	15.80,20.47
10/13/87	C-9	139	96	.596.600.580	19.59,21.03
	E-1			.655.647.621	14.57,14.32
	E-2				
10/14/87	C-9		120	.871.713.750	15.87,16.78
	E-1			.691.732.645	14.49,15.64
	E-2				
10/22/87	C-9	148	96	.554.669.604	16.10,19.14
	E-1			.491.502.522	17.12,17.79
	E-2			.483.486.491	19.29,16.89
10/29/87	C-9	155	96	.853.875.889	11.99,20.68
	E-1			.714.741.740	12.05,13.26
	E-2			.823.809.819	7.75,13.05